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Obsidian Across the Americas

Compositional Studies Conducted in the Elemental Analysis Facility at the Field Museum of Natural History

Edited by Gary M. Feinman and Danielle J. Riebe

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Front cover: Obsidian artifacts from Field Museum (Feinman and Nicholas) excavations at the Mitla Fortress and Lambityeco (Oaxaca, Mexico). Images taken by Linda M. Nicholas.
Back cover: Obsidian pre-form CB07-41-0384 sourced to Alca-1 and recovered from the Sector A Palace Complex 41A-D2 on Cerro Baúl (drawing by J. Seagard).

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Chapter 1

Chipping Away at the Past: An Introduction

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Abstract

Key to the analysis of the archaeological and geological materials presented in this volume is the Elemental Analysis Facility (EAF) and the instruments housed in the EAF at the Field Museum of Natural History. This center has grown over the past twenty years becoming a leader in compositional studies of archaeological specimens. In particular, obsidian has been intensively analyzed by researchers using various compositional techniques. While many volumes have focused on the nature of obsidian and/or its use and circulation in the past, this volume uniquely presents the research conducted on obsidian, both geological and archaeological materials, from across the Americas using the equipment housed in the EAF at the Field Museum of Natural History. In so doing, it provides a snapshot into the current status and contributions of obsidian sourcing research toward understanding trade, exchange, and mobility in the precolonial American past.

Introduction

For the past two decades, the Field Museum of Natural History has been a leader in the analysis, conservation, and preservation of archaeological and museum collections. There are an immeasurable number of researchers who have walked the museum's halls, collaborated with museum scientists and curators, and advanced our understanding of the past and helped preserve the future through a diversity of research projects. However, of particular note are those researchers and projects that have relied on the Elemental Analysis Facility (EAF) at the Field Museum.

Beginning as a casual lunch conversation between Drs. Laure Dussubieux and Heather Walder about the growing number of unpublished EAF research, the discussion has resulted in the compilation of these analytical projects in the form of two volumes, with one more in the pipeline. The first volume, edited by Dussubieux and Walder (2022), focuses on the analysis of glass bead artifacts using the laser ablation-inductively coupled plasma-mass spectrometry (LA-ICP-MS) laboratory at the EAF. This innovative volume included archaeological beads from around the world, and their analysis helped researchers reconstruct various chronological developments and human interactions. To build collaborative efforts, Dussubieux and Walder hosted a three-day workshop that allowed scholars to present their laboratory results, receive feedback from their colleagues, and incorporate the feedback into their final manuscripts. In a similar vein, the second volume, edited by Feinman and Riebe (this volume), started with a similar workshop on October 8, 2021, in which all authors presented their research in a "lightning-round" format and received feedback from the other participants and the editors. On February 4–5, 2022, a third workshop was held for the authors of the last publication that will focus on Andean ceramics and will be edited by Drs. Ryan Patrick Williams, M. Elizabeth Grávalos, and Luis Muro Ynoñán. Where the current volume differs from these other EAF compilations, however, are the materials studied and the analytical methods used. Obsidian, its origins, circulation, and use, are the focus of this volume, with most of the analyses conducted using the portable X-ray fluorescence (pXRF) devices in the EAF.

History of Elemental Analysis Facility

The origins of the EAF date to the early 2000's with Dr. Patrick Ryan Williams as the director. In 2005, the EAF became more firmly established as a leading analytical facility with the hire of research scientist and manager, Dr. Laure Dussubieux. Working together, Williams and Dussubieux have built the EAF labs – including the pXRF Lab, LA-ICP-MS Lab, and Optical Mineralogy Lab – through a series of granting initiatives from both internal sources (Negaunee Fund, Grainger Scientific

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Fund, Anthropology Alliance, Women's Board) and external sources (National Science Foundation: *BCS 0818401, BCS 1321731, BCS 1531394, BCS 0320903, BCS 1628026, BCS 2016729; BCS 1649742*). The growth of these laboratories and the investment in instrumentation has attracted researchers from all over the world, but it also has played a pivotal role in training and educating future scientists. The Field Museum and its curators and research scientists have close ties with the universities in the Chicago-land area, including Northwestern, the University of Chicago, and the University of Illinois at Chicago, and this uniquely positions interested students at these universities to learn about the different analytical techniques available in the EAF and to develop projects using these instruments and the collections at the Field Museum. Beyond training and working one-on-one with interested students, Williams and Dussubieux also developed and co-instruct a course, *Analytical Archaeology* (ANTH 494, UIC), that focuses on archaeometry and requires students to come up with a semester project utilizing one specific analytical technique.

Promotion of the EAF goes beyond the classroom to the public at large. The museum hosts a bi-annual event known as Museum Nights, and every year the EAF has a booth for the public to learn more about the benefits of the facility. Often the pXRF devices are on display, and interested people can have objects tested to determine their composition and sometimes their authenticity. In 2018, Dussubieux, along with Drs. Carla Klehm and Danielle Riebe, organized a formal workshop that was open to the public and presented a wide range of compositional research conducted in the EAF. Similar platforms for research dissemination are intended to be held in the future.

The EAF, and those running it, have sought to create more than just a research center, and as the EAF has grown, so too has its impact. Over the past twenty plus years, the EAF has been instrumental in building collaborations, educating the public, and training future scientists. By investing and developing the labs associated with the EAF, there has been increased opportunities and methods to better reconstruct and model the archaeological past.

Discussion of Instrumentation

As previously mentioned, the EAF labs consists of the LA-ICP-MS Lab, the pXRF Lab, and the Optical Mineralogy Lab. The former two labs have been highly instrumental in compositional studies of archaeological and geological specimens. Selection of the method used to analyze the materials often comes down to several variables, including sample size, portability of sample or exportability from country of origin, number of and/or specific elements necessary to generate a distinctive compositional signature, the need for minimally destructive vs. non-destructive technique, and cost. Since the early 2000s, when the EAF was first established, instrumentation has changed, and below details a brief description of those devices housed in the LA-ICP-MS and pXRF laboratories.

LA-ICP-MS

The first major instrumentation grant for the EAF was funded by the National Science Foundation (*BCS 0320903*) and secured in 2003 by Drs. Patrick Ryan Williams, Gary Feinman, Menakshi Wadwha, and Phil Janney for a mass spectrometer and a scanning electron microscope (SEM). The original mass spectrometer purchased for the lab was a Varian Ultramass Quadrupole LA-ICP-MS with a New Wave UP213 system. While the samples could be introduced to the system as a liquid, solid sample introduction relied on specimens approximately smaller than 5cm in order to fit in the analysis chamber. This greatly limited the materials that could be studied, so to expand the abilities of the equipment and to allow larger specimens to undergo solid state sampling, collaborative efforts were made to create a modified adaptable chamber that utilized a New Wave UP266 laser ablation system.

After receiving funding in 2015, in 2016 a new mass spectrometer was purchased to replace the original. The Thermo ICAP Q quadrupole ICP-MS continued to operate with the New Wave UP213 laser ablation system, and Dussubieux worked to ensure that results generated between the old and new mass spectrometers were comparable. As before, samples could be introduced into the ICP-MS either as a vaporized solid or in a liquid state.

The LA-ICP-MS analytical approach produced reliable measurements for over 50 elements. While considered a minimally destructive technique, solid ablation would result in sampling craters not visible to the naked eye. At the Field Museum, LA-ICP-MS has been used to analyze non-archaeological materials (Cook *et al.* 2006), but has been heavily relied upon to study archaeological materials (Dussubieux *et al.* 2016), including ceramics or other clay objects (Dussubieux *et al.* 2007; Golitko *et al.* 2016; Kreiter *et al.* 2014; Levine *et al.* 2013; Niziolek 2013; Piscitelli *et al.* 2015; Riebe 2021; Riebe and Niziolek 2015; Riebe *et al. in press*; Sharratt *et al.* 2009, 2015; Vaughn *et al.* 2011; Williams *et al.* 2019a, 2019b), pigments (Bonjean *et al.* 2015; Halperin and Bishop 2016), metals (Dussubieux 2007; Dussubieux *et al.* 2008), stone (Goemaere *et al.* 2013; Golitko and Terrell 2012; Speer 2014), and glass (Dussubieux *et al.* 2008, 2009, 2010; Robertshaw *et al.* 2009, 2010; Schibille 2011; Walder 2013; Walder *et al.* 2021).

pXRF

Throughout the operation of the EAF, a number of different pXRF devices have been purchased and used for both conservation and research purposes, with the first device being added to the EAF around 2007 with funding from the Grainger Scientific Fund. Later additional pXRF instruments would be secured with Negaunee funding. Generally, pXRF can reliably measure between 8–15 elements, however, the number and the specific measured elements vary depending on the instrument. The aspect that makes this device so appealing resides in its portability. This enables researchers to take the device to different countries and/or to the field, conduct analyses on materials *in situ*, and/or study those materials that cannot leave the country.

In total, four different pXRF devices have been housed in the EAF pXRF Laboratory, including an Innov-X, a Bruker TRAcER III-V, a Bruker TRAcER III-SD, and a Niton XL3t 950 GOLDD+. While these devices also have been used to study ceramics (Sharratt *et al.* 2019; Williams *et al.* 2012) and metals (Dussubieux and Walder 2015), a majority of the compositional studies utilizing the pXRF instruments in the EAF have focused on volcanic materials, such as basalt (Hastorf *et al. in press*; Janusek and Williams 2016; Janusek *et al.* 2012; Palumbo *et al.* 2015; Williams *et al.* 2015) and obsidian (Bélisle *et al.* 2020; Feinman *et al.* 2013, 2018, 2019a, 2019b; Golitko and Feinman 2015; Golitko *et al.* 2010, 2012; Meierhoff *et al.* 2010; Millhauser *et al.* 2011, 2015; Moholy-Nagy *et al.* 2013; O'Shea *et al.* 2021; Riebe 2018, 2019, 2021; Riebe *et al.* 2018, *in press*; Ruka *et al.* 2019).

Volume Contributions

The recent EAF-focused volume (Dussubieux and Walder 2022), as well as the current one, illustrate how integral the EAF has been in the lives and research of the contributors. Most of the chapters in this volume are co-authored with collaborators spanning the globe. Additionally, several of the authors (Chacaltana, Golitko, Reid, Riebe, and Sharratt) began as graduate students in the EAF and now are established research scientists. Overall, the Field Museum, its collections, and the EAF have offered researchers the opportunity to advance new lines of research, specifically as they relate to networks and the movement of people and goods. Many of the contributions in the volume highlight the reliance on existing collections at the Field Museum or other collaborating institutions, as well as the development of new investigatory methods. Together, the chapters explore a variety of regions, time periods, and topics, but all contribute to the advancement and development of anthropological research, focused on trade, exchange, and mobility, through compositional studies. Specifically, this volume presents the results of compositional studies conducted in the pXRF Laboratory of the EAF at the Field Museum and focuses on geological and archaeological obsidians from across the Americas. Although numerous techniques are available for compositionally studying obsidian (see Chapter 2 for further discussion), pXRF is an expedient and efficient technique for sourcing the geological material. From utilitarian to ornamental, obsidian has been used by peoples for thousands of years. While the material is unique in terms of its composition as a volcanic rock, its acquisition, use, and alteration by people is truly what makes the silicious object of remarkable importance for archaeologists.

The volume is divided into three sections based on geography (North America, Mesoamerica, and South America), and the chapters cover a wide breadth of archaeological topics. Several chapters deal with obsidian procurement patterns in specific regions (see Nicholas *et al.* – Chapter 5; Williams *et al.* – Chapter 10) or across vast expanses of land (Golitko *et al.* – Chapter 3; Riebe *et al.* – Chapter 4; Feinman *et al.* – Chapter 8). Other chapters focus on individual sites to reconstruct changes in procurement patterns and intra-site material distribution (see Moholy-Nagy – Chapter 6), as well as highlight the role of marketplaces in the manufacture and distribution of finished goods (Cap – Chapter 7). Finally, several chapters focus on issues related to further developing archaeometric research through increased inter-laboratory collaborations (see Riebe *et al.* – Chapter 2) and the improvement of analytical techniques (see Reid *et al.* – Chapter 9). Together, the case studies in the volume explore the ways in which obsidian analyses have been used to investigate multi-scalar interactions, socio-economic exchanges, and socio-cultural developments in the past (see Chapter 11 for further elaboration). Several chapters (especially 4 and 8) highlight the great potential of expanded sample sizes that can be achieved through the use of pXRF. Large samples allow analysis to extend beyond presence-absence observations and to reveal more detailed patterns of quantitative variation. As technology continues to advance, so too will the methods used by researchers to study the archaeological record. In that sense, it is fascinating to view the tools of today as a means to study the tools of the past.

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Chapter 2

Extraordinary Claims Require Extraordinary Evidence: The Role of Inter-Laboratory Collaborations in a Lake Huron Archaeological Discovery

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Abstract

Archaeometric techniques are used in every facet of modern archaeology: from site discovery to laboratory analysis. The increased incorporation and adaptation of various technologies and their scientific applications has resulted in new lines of evidence for understanding past behavior. However, the rapid ascent of new techniques into archaeological science has also resulted in a multitude of issues related to technique accessibility and/or applicability, measures of quality control, and use and interpretation of resultant data. One way to mitigate these issues is through increased inter-laboratory collaborations. Generally speaking, most inter-laboratory studies are conducted to illustrate the reproducibility and replicability of results between instruments/facilities, while overlooking how these types of collaborations can bolster archaeological research and refine results through multiple discrete analyses. After briefly discussing the history of science in archaeology, this paper will present a case study featuring an inter-laboratory collaboration between three archaeological science facilities in the United States to study obsidian recovered from a submerged early Holocene site in Lake Huron. This collaboration allowed for the determination that the obsidian originated from a geologic source in Oregon located over 4,000km away. The results highlight both the need and the significance of collaborative archaeological science.

Introduction

Over the past 70 years, the field of archaeology has rapidly grown in large part due to the development of new technologies and their integration into the discipline. This incorporation of technology has impacted every phase of archaeological research, from site identification and investigation to material analysis, and it has inadvertently contributed to increased specialization within archaeology. In particular, archaeometry, sometimes referred to as archaeological science, has emerged as a specialization that relies on a variety of methods to analyze various types of anthropogenically modified materials. While specialization has benefited the discipline as a whole, it has also caused schisms and factions that pit scientists against humanists. In reality, archaeology straddles both arenas since the main purpose of the field is to extract as much evidence from any recovered materials as possible to better understand and reconstruct the human past. Or, in other words, there should be "a symmetrical form of analysis that focuses not only on the description and characterization of the material properties of artefacts (the traditional preserve of archaeometry), but also on how those material properties intervene in the social lives of people (the traditional concern of theoretical archaeology)" (Jones 2004: 335). With this approach in mind, instead of dividing archaeologists, the developments in the field should encourage researchers with varying interests and specialties to work together. The purpose of this chapter is therefore twofold: after briefly discussing how technology has impacted archaeology with particular attention to archaeometry and compositional studies, a solution to the growing issues that have arisen due to technological integration will be presented in the form of a case study featuring the results of a successful multi-laboratory collaboration studying two obsidian artifacts recovered from underwater excavations in Lake Huron.

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Rise of Technology in Archaeology

Early studies on various archaeological materials from the 1800's relied heavily on emerging chemical analyses (see Davy 1815; Layard 1853; Richards 1895; Schliemann 1878). Of course, these studies were met with varying degrees of success and the analytical methods and techniques have continued to be refined over time. The first half of the 20th century was characterized by tremendous leaps and bounds in scientific advances, and these breakthroughs continued to occur at an increasing rate after World War II (Pollard *et al.* 2007). Between the 1950's and 1960's, archaeology in North America underwent a revolutionary theoretical shift. 'New Archaeology,' or processual archaeology, was promoted as a break from the 'old regime' and its culture-historical focus to match the anthropological study of "explain[ing] the full range of similarities and differences in culture behavior" and the processes that created cultural variation (Trigger 2006: 394). While this anthropological premise had been touted before by individuals like Kidder (1935) and Taylor (1948), the big difference with New Archaeology was the systematic analysis of archaeological materials to better infer and explain past social processes and the adoption of the scientific method of observation and hypothesis testing to facilitate in deductive reasoning (Trigger 2006). The change in archaeological theory combined with scientific advances resulted in a heavy reliance on new and developing technology in archaeology.

Archaeological excavations are considered to be "unrepeatable scientific experiments" (Pollard *et al.* 2007: 4) and, as Flannery's *Old Timer* character emphasizes, "Archaeology is the only branch of anthropology where we kill our informants in the process of studying them" (1982: 275). Recognition of the destructiveness of excavations and, in some cases the destruction of archaeological materials, encouraged archaeologists to conduct robust investigations that were inclusive of as many analytical techniques as possible, which ultimately meant the adoption and integration of new scientific technology. Archaeometry as a specialization therefore emerged as a result of the promotion of the sciences in archaeology. This subject is comprised of five main areas of study, including 1) dating techniques, 2) site and/or feature identification, 3) ascertaining artifact-use, 4) manufacture and technology analysis, and 5) compositional and provenance studies (Ehrenreich 1995; Liritzis *et al.* 2020). All areas have undergone extensive methodological growth, but in particular, studies on provenance have experienced significant developments in terms of techniques, accessibility, and anthropological impact.

Compositional Analysis

There are a number of different techniques that have been used to compositionally characterize archaeological materials, such as inductively coupled plasma-mass spectrometry (ICP–MS), neutron activation analysis (NAA), proton-induced X-ray emission and proton-induced gamma ray emission spectrometry (PIXE–PIGME), mass spectrometry (MS), and X-ray fluorescence (XRF; in this article we are specifically relying on energy dispersive or ED-XRF). The physics and the geochemistry associated with the different techniques vary, and this has been a growing point of contention in the field (see Frahm 2013, 2014; Jones 2004; Shackley 2008). In addition to technique familiarity, there are several other factors to consider when determining the appropriate analytical route, including cost, availability, degree of destruction, and applicability (Rapp, Jr. and Hill 1998). Many of the techniques listed above require instrumentation that has steep initial and upkeep costs that restrict their widespread availability. This then snowballs, as limited availability restricts access to the techniques, resulting in an inability to become familiar with the devices.

Perhaps because of these issues, in recent years XRF has taken the archaeometric arena by storm as being one of the most inexpensive, readily accessible, and non-destructive analytical devices. While other techniques, such as NAA (see Glascock *et al.* 1994; Gordus *et al.* 1968) and ICP-MS (Speakman *et al.* 2007), have been widely used to characterize geological and archaeological obsidian artifacts, XRF has gained popularity in large part due to the low cost associated with the analysis and the instrument's possible portability (pXRF) that allows for potential analyses to be conducted on the fly and/or in the field (Table 2.1).

Artifacts made of or containing metals, ceramics, pigments, bones, and stones, have been analyzed with XRF, but chief amongst the analyzed materials is obsidian. Considered to be "one of *the* success stories of archaeometry" (Carter *et al.* 2005: 285), obsidian characterization has become a focal point for provenance studies. This highly silicious and relatively homogenous material is the product of distinct volcanic activities and specific thermal conditions that result in distinguishable geochemical signatures. From an archaeological perspective, obsidian use and human modification of the material is recorded as far back as 1.8 mya (Piperno *et al.* 2009). Provenance studies on the material have been useful for reconstructing early patterns of exchange, how these patterns change over time, and the broader socio-cultural implications associated with these interactions (Pollard and Heron 2008;

Table 2.1. Table adapted and updated from Glascock 2010 comparing X-ray fluorescence and neutron activation analysis

Comparison of XRF and NAA		
	XRF	*NAA*
Availability	Many lab-based XRF facilities	Nuclear reactor is required
	Number of portable units is increasing rapidly	Number of locations is very limited
	Moderate training is required as it relates to device set-up, maintenance, and evaluation of instrument performance	Special training in handling of radioactive materials is required
	Portable units allow for on-the-fly analysis in the field	Radioactive waste is produced
Sample requirements	Preparation is minimal to none	Encapsulate samples in clean containers
	Nondestructive	Slightly to completely destructive (method dependent)
Analytical	Surface analysis (mostly)	Bulk analysis
	10–30 elements (instrument dependent)	25–30+ elements
	Sensitivity at parts per million levels for best elements	Sensitivity at parts per million and parts per billion levels for most elements
	Rapid turnaround	Days or weeks may be necessary to complete analysis
	Good accuracy	Excellent accuracy
	Good precision	Excellent precision
	Due to matrix effects, multiple standards are required for a good calibration	Single standard can be used for calibration
	Sample area >0.75 cm2	Sample weight >5 mg
Interlaboratory comparison	Fair to good	Excellent
	Depends on equipment and calibration methods used	Consistent and reliable between NAA labs, if the same standard(s) are used
Analytical cost	Standard rates: $25–45/sample	Standard rates: $100/sample
	Subsidized rates: $0–25/sample	Subsidized rates: $25–40/sample

Renfrew *et al.* 1968). Therefore, the anthropological benefits in association with the compositional merits have resulted in increased attention and publication of obsidian materials (Freund 2013; Shackley 2008).

The compositional data accumulated using the various techniques has produced an in-depth, geochemical understanding of a variety of archaeological materials, but again, the best studied material, with the most robust databases, is obsidian geological sources. Shackley, however, so rightly points out, because "these homogeneous, disordered, silicic glasses can be so precisely characterized, the potential abuses are much greater" (2008: 198). Unfortunately, archaeometric abuses as they pertain to compositional studies in particular are abundant. One of the biggest issues with archaeometry is the lack of training and education in physics and chemistry within the field of archaeology (DeAtley and Bishop 1991; Killick and Young 1997; Olin 1982). Archaeometric techniques rely heavily on these two disciplines and yet, most programs in North America do not offer dedicated certificates or degrees in archaeological science (Shackley 2008: 206). The lack of training paired with more accessible techniques, such as pXRF, have in some instances exacerbated concerns as more individuals are utilizing technology without proper training.

Moreover, since all compositional methods are continuing to evolve, the protocols are continuously developing and not everyone agrees as to what protocols should be promoted and enforced as the gold standard (Pollard and Bray 2007). Concerns over the physical size of the sample (see Ferguson 2012; Hughes 2010), as well as standards and calibrations (see Ferguson 2012; Harbottle 1982; Heginbotham *et al.* 2010; Liritzis and Zacharuas 2011; Shackley 2010; Speakman *et al.* 2007), have arisen over the years and have contributed to inconsistencies in technical application and, in some cases, errors in research. Additionally, researchers do not always agree on what information can be gleaned from the materials analyzed. There are some p-XRF specialists who believe that the focus of compositional studies should be on generating categories or creating a usable typology to infer about human behavior. According to Frahm, "Sourcing is archaeology, specifically a form of archaeological typology. We endeavour to sort artefacts into types that correspond to the materials' geographical origins and to interpret any patterns in terms of human behaviour. There are different approaches to create types. Geochemical measurements are the most common, but such measurements are not our goal. Our questions are archaeological, so our sourcing 'results' should be archaeological" (2013: 1445). However, utilizing scientific techniques poorly or generating data that is not useful to all interested researchers (i.e., archaeologists, geologists, and other geoscientists) encourages shoddy research that does little to advance the field of anthropological archaeology.

Even when archaeometric devices and the principles of physics and chemistry are well-understood, mistakes in compositional studies can occur. For instance, in 2016, D. Riebe used a pXRF device at the Field Museum of Natural History in Chicago (hereafter Field Museum) to compositionally analyze obsidian artifacts from numerous sites excavated by Paul S. Martin in the American Southwest primarily between the 1930s and the 1960s. A formal inventory of all materials in the 1990s renewed interest in the collection generating significant research (Chazin and Nash 2013; Koons and Nash 2015; McBrinn 2005; Nash 2005, 2006; Nash and Koons 2015), which spurred on Riebe's own interest in the obsidian artifacts housed in the collection. While the Field Museum does have some geological samples from different sources in the Southwest, an attempt was made to augment the missing geological source data with previously published compositional results by Shackley (2005; see http://www.swxrflab.net/swobsrcs.htm). This approach is generally discouraged in the archaeometric arena in favor of all geological and archaeological materials being analyzed using the same device to more accurately determine source origination (Ferguson 2012). However, this was considered by the authors to be an exploratory study and the results for only one site, O Block Cave, were initially published (Riebe *et al.* 2018). The compositional results for all obsidian artifacts in the collection were presented at the 16th Biennial Southwest Symposium in 2018 where one of the authors of this chapter (Ferguson) took an interest in the project and offered assistance. Ferguson provided samples for all Southwestern obsidian geological sources to the Field Museum for analysis, and individually analyzed all of the obsidian in the Martin Collection. A reanalysis of the published data from O Block Cave (Riebe *et al.* 2019) determined that approximately four percent of the samples were misassigned. Fortunately, this did not greatly impact the previously identified patterns of obsidian exploitation in the Southwest over time and we were able to expand the reanalysis to include all samples in the Martin collection. We were able to correct any misassignments for the obsidian artifacts before publishing the results for the entire Martin collection (Riebe *et al. in press*). Collaboration, correction of the data through publication, as well as admission of human error, has advanced research in the Southwest, while illustrating the necessity of analyzing geological and archaeological materials with the same analytical device, analytical conditions, and calibration.

The Solution – Inter-disciplinary Collaborations

With increasing archaeometric misuses and specialization, an effective way to address these concerns is to increase collaborative efforts between researchers. This is not the first paper to raise a "call to action" so to speak, and it must be noted that in recent years several papers have come out detailing the benefits of collaborative research. For instance, Millhauser *et al.* (2018) conducted an inter-laboratory study to elementally characterize the Paredón obsidian sub-sources from Mesoamerica using INAA and XRF at the MURR, the Elemental Analysis Facility (EAF) at the Field Museum, and the Research Laboratories of Archaeology (RLA) at the University of North Carolina at Chapel Hill. The study concluded that challenges emerged between laboratories and teams, but the data obtained definitively allowed for the differentiation of the sub-sources, which will ultimately challenge previous conclusions about obsidian exploitation in the

Table 2.2. Elemental concentrations for all compositional analyses conducted on the archaeological specimens and the geological samples. All trace element values reported in parts per million (ppm). NM = Not Measured

Compositional Results						
ED-XRF Data (ppm) - Field Museum, Elemental Analysis Facility	Rb	Sr	Y	Zr	Nb	Ba
Specimen 105-1	125	45	66	364	26	NM
Specimen 105-2	95	31	40	238	16	NM
ED-XRF Data (ppm) - Northwest Research Obsidian Studies Laboratory	Rb	Sr	Y	Zr	Nb	Ba
Wagontire Mean Values (n=61)	107	43	55	330	21	1441
Wagonture Standard Deviations (n=61)	4	2	2	3	2	70
Specimen 105-1	115	48	52	360	25	942
Specimen 105-2	102	46	46	297	19	NM
NAA Short Irradiation Data (ppm) - MURR	Na	Al	K	Mn	Ba	Dy
Wagontire Mean Values (n=6)	33286	71001	35924	480.2	1425	9.12
Wagonture Standard Deviations (n=6)	644	2436	1214	3.2	27	0.29
Specimen 105-1	35230	72735	35515	497.4	1545.1	8.91
Specimen 105-2	35522	36622	36622	510.0	1508.2	9.13

region (Millhauser *et al.* 2018: 466). In addition to inter-laboratory studies, other researchers are attempting to broaden access to materials in order to build databases as well as collaborations. Suda *et al.* (2018) recount their use of multiple analytical techniques between several labs to better compositionally characterize two different obsidian sources in Japan. The article ends by offering free obsidian geological specimens to other labs and researchers to increase source data (Suda *et al.* 2018: 391). Both of these studies illustrate how collaborative efforts result in better archaeology.

In a similar strain, the authors of this chapter have worked together over the past three years to study and publish the data derived from the compositional analysis of two pieces of obsidian recovered from Lake Huron. The results have recently been published (see O'Shea *et al.* 2021), so the focus of this case study is specifically on the contributions of each lab and how the inter-laboratory research resulted in new information about early Holocene networks in North America.

An Epic Obsidian Journey – From Site to Source and Source to Site

The North American Great Lakes are well-known bodies of water, but early occupation around the lakes is not well understood due to significant fluctuations in water levels. During the Lake Stanley low water stage, ca. 10,000–8,000 BP, a large swath of land was exposed in the Lake Huron Basin that linked modern-day Michigan with Ontario (Lewis 2016; Lewis *et al.* 2007). The same area is now part of a submerged paleolandscape and since 2008, O'Shea and his team have been conducting underwater archaeological research in Lake Huron to investigate human occupation in the area (Lemke and O'Shea 2019; O'Shea and Meadows 2009; O'Shea *et al.* 2014).

In 2013 the DA-1 find spot was excavated and from this location two dark, silicious appearing specimens were recovered (see Figure 2.1). While visual inspection has traditionally been an initial way to typologically identify and determine the geological source of materials (see Weisler and Clague 1998), these items were met with extreme skepticism as similar looking, but smaller specimens from previous excavations turned out to be anthracite coal. Compositional analysis was deemed necessary to determine what was actually recovered from beneath Lake Huron and thus began the compositional analytical journey of these artifacts (see Table 2.2 for all compositional results).

The two samples were first shipped to Riebe at the EAF at the Field Museum. Compositional analysis with a Bruker TRAcER III-SD pXRF confirmed that both samples

Figure 2.1. Location of the geological source in the American Northwest with a close-up map of the Lake Huron Basin in the American Midwest. The archaeological materials were recovered from the DA-1 excavation unit.

were rhyolitic in composition and likely obsidian. The Economic Geological Collection (EGC) at the Field Museum has a number of different curated specimens from obsidian geological sources all over the world and, using the analytical devices in the EAF, a database of obsidian geological signatures was created. Though some North American obsidian sources are included in this database, Mesoamerican, South American, South East Asian, Mediterranean, and Eastern European sources make up a majority of the source data. After the Lake Huron samples were identified as compositionally obsidian, the next step was to determine the geological origins. The EGC database was consulted, but there was no match among the North American sources on file. At that point, another lab had to be consulted, and Ferguson at MURR was the logical next colleague to contact.

The samples were sent to MURR and Ferguson analyzed them with XRF, reconfirming their classification as obsidian. MURR has an impressive geological signature database, but the largest compositional database has been generated using NAA. Given the small size of the artifacts, the unique submerged context of the finds, as well as their potential archaeological significance, non-destructive techniques were necessary for this study. This led Ferguson to suggest that the samples be sent to A. Nyers at the Northwest Research Obsidian Studies Laboratory who has access to a robust database of sources in the Northwestern United States (the most likely source location for obsidian recovered from eastern North America). Nyers analyzed the specimens by XRF and the compositional signatures were similar to three sources in Central Oregon. Generally speaking, only a select few elements are necessary to characterize obsidian sources (e.g., Rb, Sr, Y, Zr, Nb, Ba). However, sometimes the measurements of additional elements are required, making XRF a complementary technique to other analytical methods such as INAA. The samples were therefore sent back to MURR for analysis using short irradiation NAA. Most NAA studies at MURR involve both long and short irradiation. This provides a large suite of around 30 elemental concentrations, but long irradiation generally requires breaking the sample into small pieces and the analysis produces long-term radioactivity that prevents the return of the samples. Short NAA can be a non-destructive technique (assuming specimens are small enough to fit in the short irradiation vials) that allows for a small suite of elements to be measured and for the compositional results to be compared with MURR's robust geological source database. The journey that the samples took between the three laboratories, the different compositional analyses, and the involvement of different specialists finally resulted in the identification of the geological source for the artifacts: the Wagontire source in Central Oregon (Figure 2.1). These results signify connective networks during the Late Pleistocene that span from the West Coast to the North American Great Lakes. Continued work at the submerged site will hopefully provide more data that will augment information about the expansive networks in place and further inform about early human behaviors.

Discussion

So why collaborate? Archaeology already relies on an array of disciplines, such as geography, geology, physics, chemistry, biology, and sociology, requiring familiarity with multiple disciplines and encouraging collaboration between specialists. As technology continues to develop and as archaeologists continue to integrate these new technologies into their work, it is likely that archaeological specialization will continue to increase. While schisms can emerge, one way to mitigate this is through cooperation and collaboration. For the obsidian artifacts from Lake Huron, collaboration was essential for discerning the geological source of the artifacts. The different techniques of XRF and NAA enabled researchers to identify the specific source of the artifacts rather than just the general region and reproduce the results. Understanding patterns of lithic resource use is a vital component of archaeology, particularly for time periods of hunter-gatherer occupation where stone was an essential technology. Identifying source locations can help archaeologists reconstruct patterns of movement, trade and exchange, and resource extraction. By isolating the exact source, it provides archaeologists with valuable information regarding early exploitation of geological sources and long-distance exchange in North America. Most lithic assemblages in early North American archaeological sites display unique use patterns for different stone sources, and the proportion of exotic materials to local materials is a common measure of a group's mobility, regional and extra-regional travel and exchange, and settlement patterns. As opposed to later periods in which sources from Idaho and Montana, including Obsidian Cliff, Teton Pass/Fish Creek, and Malad, are identified at numerous Middle Woodland and Late Archaic sites in the American Midwest (see Golitko *et al.* in this volume), the current study illustrates exchange networks between the American Midwest and a source (Wagontire in Central Oregon) located further to the west and one that does not appear in later Holocene contexts. The great distance between the source location and the artifacts' context in the Lake Huron case study is among the greatest ever recorded for an archaeological site, and provides insight in social connectedness across the continent 9000 years ago. While long-distance exchange networks are informative in and of themselves, these results hint at even larger, more extraordinary claims. The same Pleistocene exchange network identified in this study may be a remnant of earlier human movements across North America, but only additional research will help to test this idea.

On a more practical level, this collaborative project is unique in this volume, in that it focuses on obsidian artifacts from a submerged context. Submerged prehistoric archaeology continues to emerge as a field and new results such as those from the Lake Huron study help quell critiques that sites of great antiquity would not survive inundation. The obsidian artifacts are clearly human manufactured materials and are not the result of natural processes occurring before or after the site was submerged. Instead, the definitive sourcing further reifies the cultural nature of the Lake Huron sites and the unique data they have preserved. As work at Lake Huron continues and as more obsidian materials are recovered, the current study acts as a starting point for further developing and refining these early long-distance exchange networks across North America. Overall, the convergent results from the three labs and multiple techniques provided critical empirical support for extraordinary and unexpected sourcing of the submerged archaeological finds.

Conclusion

The purpose of this paper was to present the state of archaeological collaborative efforts and how technology is playing a key role in increased collaborations. Overall, good archaeology and good archaeological science are the products of good practices and good practices ensure that the results obtained are accurate, replicable, and comparable. Comparability, in particular, should not just be between different archaeological compositional studies, but on the broader inter-disciplinary scale. Through inter-laboratory and collegial collaborations, archaeologists have the ability to use different techniques and are able to rely on the various skill sets of their colleagues to ensure that research conducted is beyond reproach - though that is not to say that conclusions cannot be challenged should new techniques or data become available. The collaborative research conducted on the Lake Huron obsidian artifacts illustrates how specialists at multiple institutions can work together to not only determine the geological source of the artifacts, but also to pose new conclusions about early North American exchange networks.

Technology will inevitably continue to be incorporated into the field of archaeology, but it should be done in a manner that unites the field and promotes sound scientific research. In a 2013 article about the use and expediency of pXRF, Frahm facetiously remarked that archaeologists should "[...] get out there and play scientist!" (1448). Moving forward, however, archaeologists should not play at anything; they should *be* scientists because they *are* scientists. Growing technological innovations offer the opportunity for archaeologists to reconstruct past human behaviors in novel ways, and it is necessary to collaborate with others to ensure that the integration and application of techniques advances the field as a whole. Inter-laboratory collaboration will continue to be a crucial and ever-developing aspect of archaeological research and by working together extraordinary discoveries can and will be achieved.

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Chapter 3

A (Near) Comprehensive Chemical Characterization of Obsidian in the Field Museum Collections from the Hopewell Site, Ross County, Ohio

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Abstract

The Middle Woodland period Hopewell archaeological culture (*c.* 200 BC – AD 500) is notable for the development and intensification of continental scale networks through which objects and materials were acquired by inhabitants of eastern North America. Obsidian is present in many Middle Woodland sites, but sources of this material are far to the west in the Rocky Mountains and Southwest. The eponymous Hopewell site, in Ross County, Ohio, was excavated several times, including by W.K. Moorehead between 1891–1892 to provide material for display at the 1893 World's Columbian Exposition. Subsequently, the resulting materials were incorporated into the early collections of the Field Museum of Natural History. The Hopewell site is notable for the huge volume of imported material present there, including large bifaces made of obsidian. These were compositionally analyzed by James Griffin and colleagues in the late 1960s. Their analyses (and several subsequent studies) demonstrated that two sources, Obsidian Cliff (Wyoming), and Bear Gulch/Camas-Dry Creek were present in the Hopewell assemblage. However, large portions of this collection remain unanalyzed. Here, we use non-destructive PXRF analysis to characterize the majority of obsidian currently included in the Field Museum Hopewell collection. In common with earlier analyses, we find that Obsidian Cliff and Bear Gulch obsidians comprise the bulk of the collection, with the exception of a single piece from the Malad source flow (Idaho). Two other unidentified source flows may be present in the assemblage, although this will require further work to confirm. In common with earlier studies, we find no evidence for production using any material other than Obsidian Cliff volcanic glass, suggesting that bifaces made on other source materials may have been acquired from elsewhere.

Introduction

The Hopewell Site is one of a number of large mounded enclosures located in the Scioto River valley of Ohio near modern day Chillicothe. The site also lends its name to the Middle Woodland period (*c.* 200 BC – AD 500) archaeological cultures/traditions of Ohio, Indiana, Illinois, and Wisconsin and parts of Tennessee, Missouri, and Iowa. As Yerkes (2006: 50) has written, 'The people we call the Hopewell are one of the best-known but least-understood prehistoric cultures in the world. Their artifacts, burials, mounds, and earthworks are spectacular and are the most elaborate built environment in the prehistoric United States...For many, the magnitude of Hopewell earthwork construction and the abundance of exotic artifacts is difficult to explain in the absence of well-developed agriculture, a hierarchical social structure, craft specialization, and centralized redistribution.' These mounded sites, particularly those in the Scioto Valley of Ohio, are well known for finds of 'exotic' goods transported over hundreds and even thousands of miles from their sources. This includes copper from the northern Great Lakes region of Michigan and Ontario, mica from the Atlantic Coast, shark's teeth from the Gulf or Atlantic coasts, Knife River Flint from the Dakotas, and possibly grizzly bear teeth from the Rocky Mountains (DeBoer 2004). The furthest travelled of these materials is obsidian, which appears in many Middle Woodland throughout the Midwest and late Archaic sites (c. 3000–1500 BP) on the northern Plains (DeBoer 2004).

The structure and social underpinnings of this 'Hopewell Interaction Sphere' (Caldwell 1964) remain

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much debated. Some have viewed this transport and acquisition as part of elite strategies within a largely sedentary society designed to build social capital through the conspicuous display of exotic goods, with mounded centers as the focal points of competing polities (e.g., Greber 2006; Pacheco and Dancey 2006). Others view the presence of exotic goods and construction of large mounded sites as part of building social cohesion amongst more mobile dispersed populations at least partially reliant on hunting and gathering (e.g, Cowan 2006; Yerkes 2006). Although not excluding these possibilities, it has also been suggested that the materials found at Hopewell and other mounded Middle Woodland sites may have been brought there from afar by individuals undertaking pilgrimages to the Scioto River Valley (e.g., Spielman 2009).

Several obsidian sourcing studies have been conducted on the Hopewell site assemblage since James Griffin and colleagues' initial studies of the mid-1960s (Griffin 1965; Griffin *et al.* 1969), and have consistently identified two sources at the site, Obsidian Cliff (WY) and Bear Gulch (ID). These sources have also been identified at other Middle Woodland and Late Archaic sites eastwards of these source occurrences. However, questions remain as to the composition of the Hopewell assemblage and the relationship between Hopewell, where the vast majority of all Middle Woodland obsidian is concentrated, and other contemporaneous sites. In this chapter, we present new sourcing results for obsidian from the Hopewell site presently housed in the collections of the Field Museum of Natural History using portable X-ray Fluorescence Spectrometry (PXRF). Combined with prior sourcing results on the Field Museum Hopewell obsidian collection, our results can be considered a near comprehensive source characterization of the extant assemblage housed at the Field. As in prior studies, we find that the majority of obsidian (*c.* 70–90%) at Hopewell derives from the Obsidian Cliff source in Wyoming, with c. 10–20% originating at Bear Gulch, Idaho. We document the presence of a single piece of obsidian from the Malad source (Idaho), which is present elsewhere in the Hopewell area, but was previously not documented at Hopewell itself. Our new data provide no evidence for production waste from sources other than Obsidian Cliff at Hopewell, lending some support to arguments by Hughes (2006) and DeBoer (2004) that Bear Gulch obsidian arrived at the Hopewell site either through different routes of transport and/or at a different time than Obsidian Cliff volcanic glass. If so, the Hopewell assemblage is only partially consistent with Griffin's (1965) 'one shot' hypothesis for obsidian acquisition and redistribution during the Middle Woodland period.

The Hopewell Site and the Field Museum Hopewell collection

The Hopewell Site

What is today referred to as Hopewell Mounds, or the Hopewell site, is one of a number of large mounded enclosures located along the Scioto River and its tributaries near Chillicothe, Ohio (Lynott 2009). The site has been investigated numerous times—the earliest investigations were carried out by Caleb Atwater during the 1820s. Further investigations were conducted by Ephraim Squier and Edwin Davis in 1845 (Squier and Davis 1848). These early projects remain important because they provide some of the most complete maps of the site, which was largely destroyed by agricultural activity during the 20th century, and because these early investigations also first identified the site as having an assemblage that is uniquely rich in objects made on imported materials. As mapped by Atwater, Squier, and Davis, the site consists of two large square enclosures, the larger enclosing more than 100 acres, as well as a number of large circular or elongated mounds and smaller enclosures (Greber and Ruhl 1989).

The most extensive excavations of the site were undertaken by William K. Moorehead during 1891 and 1892. Moorehead was employed by Frederick Ward Putnam to collect materials for the upcoming World's Columbian Exposition of 1893 to be held in Jackson Park in Chicago. The mounded sites of southern Ohio were selected for excavation based on earlier publications of the assemblage at Hopewell in hopes of recovering similar 'exotic' materials. After initial excavations at the Fort Ancient site failed to uncover a similar density of imported materials and elaborate artifacts, Moorehead turned his attention back to Hopewell. Between September 1891 and January 1892, Moorehead opened a number of trenches across the N-S axis of the site and excavated a number of the mounds. His work focused particularly on Mound 25, the largest at the site, which contained abundant cultural materials as well as cremation burials and plastered floors that may have been constructed for cremations. Much of the material he excavated, including most of the obsidian he recovered, was uncovered in two clay-lined depressions that he termed 'altars.' Other mounds at the site contained mica, silver, copper objects, massive deposits of flint discs, and other imported materials. Moorehead also recovered obsidian from Mound 17, located towards the northern edge of the main enclosure (Greber and Ruhl 1989; Moorehead 1922), while Squier and Davis had earlier found obsidian in Mound 9, to the immediate southeast of Mound 25.

The last major excavations at the site were conducted by Henry Clyde Shetrone and the Ohio State Historical

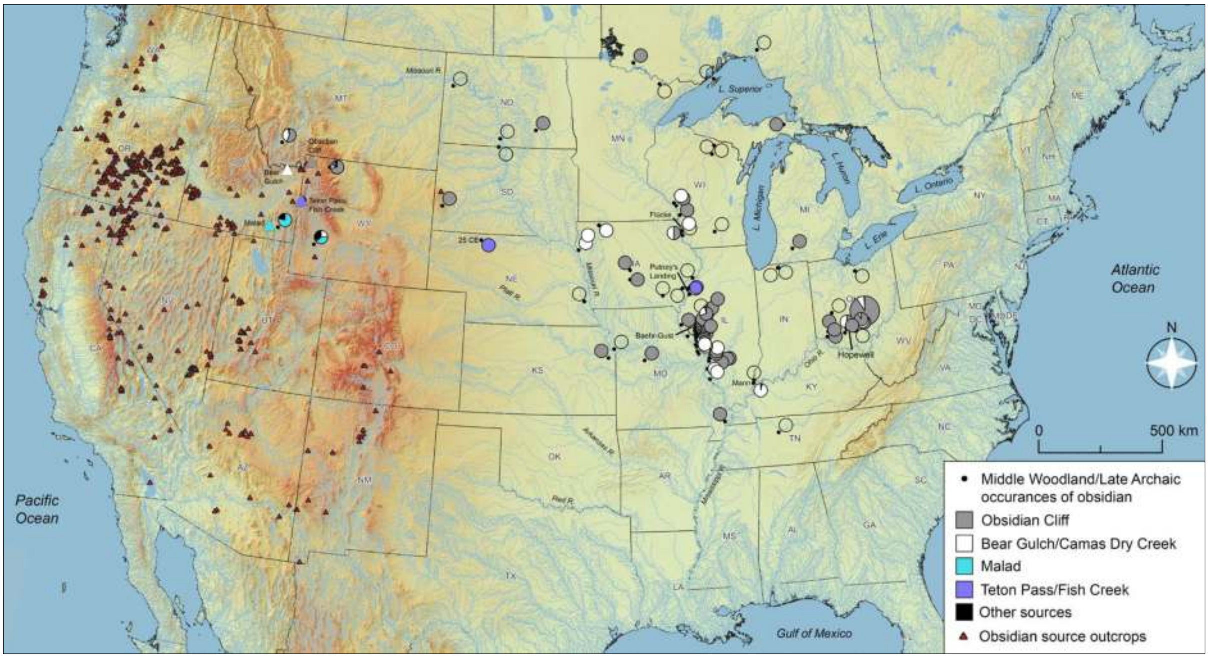

Figure 3.1. Location of Hopewell Mounds and other Middle Woodland and Late Archaic sites with relevant occurrences of obsidian. Percentages of identified sources are indicated. Open circles represent sites with obsidian from which no source assignments are reported. Data are taken from DeBoer (2004), Hughes (2006), Bucher and Skinner (2002), Mangold and Schurr (2006) and Hughes and Fortier (2007), except for Hopewell Mounds, which is based on the data reported in this chapter. Locations of obsidian sources in the continental United States are those reported by Northwest Research Obsidian Laboratory (http://obsidianlab.com/universe.html).

Society in 1922. Shetrone excavated a number of additional mounds and attempted to reexamine mounds that had been previously explored by Squier, Davis, and Moorehead. In Mound 11, Shetrone uncovered a massive deposit of obsidian debitage associated with two cremation burials (Hatch *et al.* 1990; Shetrone 1926). This single deposit contained more than 10,000 individual pieces of obsidian estimated to weigh nearly 300 lbs (Griffin 1969). Little work has been carried out at Hopewell since Shetrone's excavations—the site was privately owned until the early 1980s, and deep plowing after World War II saw large portions of the site destroyed (Greber and Ruhl 1989). A National Park Service project during the 2000s focused on additional mapping and remote sensing work (Lynott 2009).

Interpretations of the Hopewell site and its place within Middle Woodland society have changed considerably over time. Atwater for instance believed the site to be a fortified village, and Moorehead designed some areas of the site as 'village' locations. However, recent work has found no evidence of occupation at the site during the Middle Woodland period—any habitation debris likely dates to the subsequent Late Woodland period (Pederson Weinberger 2009). Current interpretations suggest that Hopewell and other mounded sites in southern Ohio were primarily ceremonial and burial locations embedded within patterns of inter-community relationships (e.g., Hill *et al.* 2020). The dating of activity at the site also remains hampered by the nature of 19th century excavations, inconsistent recording, and subsequent destruction of large portions of the site. Hatch *et al.* (1990) performed hydration dating on obsidian from Hopewell and argued for a relatively long phase of mound construction and obsidian importation spanning nearly the entire Middle Woodland period (*c.* 100 BC – 400 AD), however, the low precision of these dates may have led them to overestimate the length of obsidian importation (Hughes 1992) at Hopewell. Other researchers (e.g., DeBoer 2004) continue to favor a much shorter chronology for the primary phase of major construction, obsidian importation, and ceremonial activity at Hopewell focused between *c.* AD 100–300/400.

The Field Museum Hopewell obsidian collection

The Field Museum in Chicago holds one of the two primary collections of obsidian from the Hopewell Site, the other being at the Ohio State Historical Society in Columbus, Ohio. The later contains the bulk of the material from Shetrone's excavations, while the obsidian recovered from Mound 9 by Squier and Davis is currently held in the collections of the British Museum. The bulk of the individual accessions of Hopewell obsidian at the Field derive from Moorehead's 1891–1892 excavations, and were incorporated into the collections of the new Field Columbian Museum after the end of the 1893 exposition. However, the extant Field collection does not contain all of the material excavated by Moorehead. Some of the material may already have been lost or sold during excavations, or during transport between the conclusion of excavations and the display of the material at the Columbian Exposition.

At the conclusion of the 1891–1892 excavations, the Hopewell material was first sent to the Harvard Peabody Museum, where it was studied and documented by Charles C. Willoughby before being sent on to Chicago for the exposition. Once the exposition closed, part of the collection was sent back to Putnam at the Harvard Peabody. While some of this material was subsequently returned to the Field Columbian Museum, at least four bifaces excavated from Mound 25 are presently in the Peabody collections (object ID 95-32-10/72791). The Moorehead collection was then moved in the early 1920s from the Field's original location on the grounds of the Columbian Exposition in Jackson Park (now the Museum of Science and Industry) to the museum's current location south of downtown Chicago (Greber and Ruhl 1989).

The Field Museum also traded, gave, or sold portions of the Hopewell collection to other individuals and organizations, including the Milwaukee Public Museum, the Museo Nacional de Antropología in Mexico City, and the University of Michigan. Some of these exchanges and sales included obsidian. One such exchange was with the Ohio State Historical Society, which resulted in some of the Moorehead material being exchanged for material from Shetrone's later excavations (Schmitz 2020). As a result of poor initial documentation, frequent movement, and these exchanges, the provenance of most obsidian objects from the Hopewell site housed in the Field Museum collections is either questionable or totally absent. Attempts have been made to make sense of the assemblage, most recently through the 'Ohio Hopewell: Prehistoric Crossroads of the American Midwest' project (http://hopewell.unl.edu/), a collaboration between the Field and University of Nebraska-Lincoln. Information about the Hopewell obsidian assemblage is largely drawn from the records compiled during that project as well as an earlier study of the site and its material assemblage by Greber and Ruhl (1989).

Obsidian in Middle Woodland assemblages and prior sourcing work

During the last two centuries of archaeological work, obsidian has been recovered from a number of Middle Woodland or other contemporaneous contexts in Missouri, Iowa, Minnesota, Wisconsin, Illinois, Tennessee, Michigan, Ohio, and along the northern edges of Lake Superior (Figure 3.1). The assemblage from Hopewell remains unique, however, both for the volume of material present and because much of this obsidian occurs in the form of large bifacial knives and points. There are exceptions to this, for instance a *c.* 10kg core found at Meredosia in the Illinois River Valley, as well as some larger bifaces found in Havana Hopewell burial mounds like Flücke, where an individual was interred with a large obsidian biface in each hand. Some of these bifaces have been described as looking more similar to Ohio styles than to more typical Havana Hopewell knives and points made on other materials (DeBoer 2004; Hughes 2006).

The sources of Middle Woodland obsidian were the subject of much speculation during the nineteenth and early twentieth centuries. Squier and Davis (1848) suggested that the Hopewell obsidian may have originated in central Mexico, a supposition largely based on their notions of culturally and racially advanced 'mound builders' derived from the populous urban societies of Mesoamerica. On the basis of geographical proximity, sources in the US Southwest were also suggested—the nearest sources of high quality obsidian to the Scioto Hopewell sites are located in the Jemez Mountains of north central New Mexico. Charles Willoughby first suggested the possibility that at least some of the material might have been obtained from further north in Wyoming and Idaho during his examination of the material from Moorehead's excavations. He noted the presence of mahogany streaking in some of the Hopewell pieces, and suggested the material might derive from Obsidian Cliff in Yellowstone National Park (Greber and Ruhl 1989: 189), one of the largest occurrences of volcanic glass in North America (Holmes 1879; MacDonald 2018).

In the mid-1960s, James Griffin and colleagues initiated a sourcing study of selected objects from Hopewell and other Middle Woodland sites using Neutron Activation Analysis (NAA). At that time, little work had been done to determine the compositions of North American obsidian source flows, but they were able to conclusively link many of the objects from Middle Woodland contexts to the Obsidian Cliff source. However, they also noted the presence of another geochemical type of obsidian, which they termed '90 type' after the mean Na/Mn ratio in those pieces (Gordus *et al.* 1968; Griffin 1965; Griffin *et al.* 1969). Later work confirmed that these '90 type' samples matched the composition of the Bear Gulch/Camas Dry Creek source in far eastern Idaho (Hughes 2006; Wright and Chaya 1985). While Mexican and Southwestern obsidians have been found in sites on the Southern Plains (but only in sites post-dating the Middle Woodland period, see Barker *et al.* 2002 and Jones *et al.* 2019), Griffin and colleagues did not find any obsidian from Mesoamerican or Southwestern sources at Hopewell or in any other Middle Woodland assemblages, nor has any subsequent study.

Griffin noted that the distribution of obsidian in Hopewell sites was unusual—ordinarily, one would anticipate a falloff in abundance with distance from source, but in the Middle Woodland period, the vast majority of obsidian appears to be concentrated at Hopewell itself. This contrasts with distribution patterns for other materials like Knife River Flint, which is present in small quantities at Hopewell but is far more abundant closer to its geological source in South Dakota (DeBoer 2004). To explain this unusual distribution, Griffin proposed his "one shot" hypothesis. As he wrote (1965: 146–147), 'the total amount of obsidian from Hopewell sites might have been obtained on one trip to Yellowstone. The implications of this "one shot" hypothesis would be that Hopewellian obsidian was obtained, distributed, and consumed within a relatively short span of time, say 25 to 50 years.' In other words, rather than representing the outcome of longer term patterns of trade and exchange between Yellowstone and intermediate sites ultimately leading to the Scioto Valley, obsidian could have been obtained on a single collecting trip to the Yellowstone area. Most or even all of the obsidian found in other Middle Woodland contexts was then obtained from Hopewell, which served as a redistributive center for this material.

Most subsequent sourcing studies of obsidian from both the Hopewell site itself and other Middle Woodland sites have served as tests of the implications of the one shot hypothesis. This included subsequent analyses by Griffin and colleagues (Gordus *et al.* 1971), as well as numerous other geochemical studies of obsidian from both other Scioto Valley Mounds (Seip, Mound City, and others) and Havana Hopewell sites further west (e.g., Anderson *et al.* 1986; Hughes and Fortier 2007; see DeBoer 2004 for a summary of some of these studies). Further obsidian from Hopewell Mounds was analyzed by Hatch and colleagues using INAA and ICP-AES (1990), and most recently by Hughes using EDXRF (2006).

Although Hatch and colleagues (1990) suggested that volcanic glasses other than Bear Gulch and Obsidian Cliff could potentially be present in the Hopewell assemblage, they did not provide any conclusive evidence linking obsidian pieces to additional sources (Hughes 1992), while Hughes's more extensive study also only identified these two source flows. However, other evidence both from Hopewell itself and other Middle Woodland assemblages suggest that the one shot hypothesis is unlikely to fully account for all Middle Woodland obsidian. Sources other than Obsidian Cliff and Bear Gulch have been found at Havana Hopewell sites—Teton Pass/Fish creek obsidian from Wyoming is present at Putney Landing in Illinois, but also further west at the 25 CE site in north central Nebraska (DeBoer 2004). Malad obsidian, from southeastern Idaho, has been recovered at the Baehr-Gust site in the Illinois River Valley (Hughes 2006), and is also present in some assemblages in Minnesota that may be contemporaneous with Hopewell (Hughes 2007).

Hughes (2006) failed to identify any Bear Gulch obsidian amongst the debitage at Hopewell, but did find evidence for Bear Gulch production waste at the Mann site in southern Indiana, and has consequently suggested that Bear Gulch obsidian may have come to Hopewell through different mechanisms than Obsidian Cliff glass. As Hughes (2006: 372) writes, 'If the "one shot" hypothesis is correct and virtually all the obsidian introduced into Ohio Hopewell sites arrived first at Mound 11, then one would expect to find formal obsidian artifacts made from Bear Gulch obsidian at Mound 11 in roughly the same proportions as at other Ohio Hopewell sites. To date, no Bear Gulch obsidian has been geochemically identified from Hopewell Mound 11 or, as debitage, at any other Hopewell mound site; but because so few samples from Mound 11 cache have chemically characterized (n=29), the case is far from closed.'

Furthermore, Obsidian Cliff material has also been recovered in Early Woodland contexts in Wisconsin and Michigan (Stoltman and Hughes 2004), and is present in low volumes in some Late Woodland contexts (Jones *et al.* 2019). This suggests that the Middle Woodland period represents more of an intensification of obsidian acquisition rather than an isolated period of importation (Hughes and Fortier 2007; Stoltman and Hughes 2004). As late as the Mississippian period, Obsidian Cliff and Bear Gulch remain the primary sources distributed along the northern Plains (Jones *et al.* 2019). Recent work in Yellowstone National Park and nearby areas of Idaho, Wyoming, and Montana have also provided insight into production and distribution patterns nearer to the sources of obsidian that found their way into Middle Woodland sites (e.g., Bohn 2007; MacDonald *et al.* 2019; McIntyre *et al.* 2013; Scheiber and Finley 2011; Smith 1999). These recent studies suggest a major intensification of obsidian quarrying at Obsidian Cliff during the Late Archaic period (MacDonald 2018), but also suggest potential routes by which different source materials traveled out of the Rockies (Scheiber and Finley 2011).

All of the sources that have been identified in Middle Woodland assemblages are present in Yellowstone itself, although Obsidian Cliff dominates assemblages there. These obsidians are also the primary ones present in sources further north and along the Missouri River, the likely primary route eastwards (*cf.* DeBoer 2004). However, Malad and Teton pass obsidians are far more common further south in Idaho and Wyoming, and available distributional data would seem to suggest a more southerly distributional route for these materials (see Figure 3.1 and Scheiber and Finley 2011). While it remains hypothetically possible that a single visit to Yellowstone could have provided all of the obsidian that subsequently entered the Hopewell area, extant data makes a more complex scenario of distribution and acquisition more likely than a 'pure' version of the one shot hypothesis.

There remain a number of issues related to understanding how and when obsidian reached the Hopewell site and how it was distributed into other areas of the Hopewell Interaction Sphere. Chronology remains a major concern, and one that can only be resolved by better dating of sites. This may be possible in some cases, but for Hopewell itself, the limitations of early excavations combined with the destruction of much of the site during the decades between Shetrone's excavations and attempts to preserve the site during the 1980s mean that little can be done to resolve chronological issues there. There are however a number of questions that can be addressed using extant collections of obsidian from Hopewell Mounds that the present study attempts to resolve:

1. What is the relative frequency of different sources at the Hopewell site, and how does this compare to their regional distribution during the Middle Woodland period?
2. Are Obsidian Cliff and Bear Gulch the only sources present at the Hopewell site, or have prior studies missed other sources that are present at low frequencies?
3. Is debitage from the Hopewell site entirely of Obsidian Cliff, or is there evidence for production waste from other source flows?
4. Are different biface forms associated with different source flows?

Materials and Methods

The Hopewell sample

The present analysis was initiated in 2010 with the intention of producing a comprehensive source characterization of all obsidian from the Hopewell site currently held in the Field Museum collections. When combined with earlier studies by Griffin and colleagues (63 pieces), Hatch and colleagues (23 pieces), and Hughes (170), our new analyses of 543 individual obsidian pieces provide a near comprehensive characterization of the existing assemblage. The primary exceptions involve a handful of bifaces (FM56016, 56086, 56775, 56782, 56784, 56798, 56799, 56805, 56807, 56820, 56832, 56834), bladelets (FM56546), and debitage (FM56594) that are either currently on display in the museum's "Ancient Americas" exhibit or were inadvertently omitted from the present sample. In many cases, our sample partially overlaps with earlier chemical studies, although because those studies rarely provided Field Museum accession numbers and instead reported laboratory specific sample numbers, it is not always possible to align our sample with prior work. We can determine the 23 pieces that were included in the Hatch *et al.* (1992) study as they destructively sampled pieces leaving distinctive square notches in those objects. Hughes (2006) does provide some FM accession numbers, including for several objects and accession lots we did not analyze. This includes debitage and bifaces from Mound 17 (FM56594).

Materials in the Field's Hopewell collections are known to come from a number of provenances within the site, including Mounds 1, 2, 3, 4, 8, 11, 17 (in Moorehead's numbering system), 20, 23, 24, and 25, and the 'village' site, an area within the western end of the main enclosure (Almazan 2005). Two flakes are attributed to Mound 11, and are the only materials in the Field Hopewell obsidian collection from Shetrone's excavations. Twenty-two objects were excavated from Mound 25 by Moorehead, most of which are either bifaces or biface fragments. While the majority of these are listed as coming from Altar I, Moorehead and Willoughby only note obsidian as having been recovered from Altar II within Mound 25 (Greber and Ruhl 1989; Moorehead 1922), so this level of provenance assignment is questionable. A single piece of angular debitage is associated with the 'village' site, while the rest of the assemblage has no further information associated with it. The bulk of our sample comprises debitage and biface fragments listed under temporary 900000 Field Museum accession numbers. These materials were discovered in a box in storage during the 1980s, and while listed as coming from Hopewell, had no other provenance information associated with them (Almazan 2005). These materials were not included in prior sourcing projects.

In his initial description of the Hopewell obsidian assemblage, Willoughby noted that most of the bifaces Moorehead excavated were broken and otherwise fragmented and some showed signs of exposure to intense heat (Greber and Ruhl 1989: 189). This is readily visible on some objects. What has been less documented is the fact that almost all of the more complete bifaces from Hopewell have at some point been reconstructed using filler of some sort, either a putty or plaster. This may have been done by Willoughby as he prepared the collections for the World's Columbian exposition, or after the materials were shipped to Chicago in advance of being displayed. As part of this partial restoration, some of the bifaces were apparently "touched up" with a matte black paint, perhaps to make the reconstructed portions less obvious. The Hopewell assemblage consists of a variety of artifact types, which we have classified into a variety of morphological categories:

Ross Knives: large bifaces with wide bases that typically have a tang and two barbs (e.g., Hughes 2006: Figure 20.2A and B). In some cases, these barbs appear to have been subsequently removed to produce a triangular base (e.g., Hughes 2006: Figure 20.2C).

Atypical Ross Knives: large bifaces that have atypical or unique morphologies including asymmetrical blades or atypical and complex basal tangs and barbs (e.g., Hughes 2006: Figure 20.3D; Greber and Ruhl 1989: Figure 6.5b).

Ovoid Knives: large bifaces having a distinctive ovoid shape when viewed from above, i.e., with tapering bases (e.g., Hughes 2006: Figure 20.2D)

Ross Points: triangular bifacial points with a tang and barbs—these are similar to Ross knives but are smaller and triangular rather than moderately ovoid (e.g., Hughes 2006: Figure 20.3E, F, and G).

Lancelet Points: bifacial points with flat bases and parallel sides (e.g, Greber and Ruhl 1989: Figure 6.5a and c).

Ovoid Points: similar to ovoid knives, but smaller, and some have a "fishtail" base on them (e.g., Hughes 2006: Figure 20.3A, B and C).

Flat-Bottomed Points: triangular points without tangs or barbs. These may be Ross points that have been modified in a manner akin to the triangular based Ross knives (e.g, Hughes 2006: Figure 20.3H).

Point and Biface Fragments: recognizable sections of bifaces that cannot be assigned to a specific category.

Bladelets and Bladelet Cores: bladelets and bladelet "bullet" cores (Greber *et al.* 2006).

Angular Debitage: angular fragments with no recognizable platform or bulb of percussion present. Some of these pieces have negative flake scars, and much of this debitage likely represents small fragments of bifaces that were not reconstructed, rather than production waste.

Flakes: debitage with recognizable platforms, bulbs of percussion, and so forth.

Flake Cores: obsidian fragments with recognizable flake scars present that are clearly not fragments of bifaces.

We also analyzed 22 objects that were listed as obsidian in the Field Museum's records, but which have chemical compositions that are clearly inconsistent with obsidian. Among these are a set of bladelets included in accession lot FM56504, which may be made on dark chert or some similar material as well as a bladelet core (FM56554.3) of what appears to be the same material. These materials are not discussed further here.

Comparative raw material samples

The present study relied on raw material samples housed in the Field Museum's 'Economic Geology' collection, compiled to assist in obsidian sourcing work on Field Museum collection objects. The bulk of these samples utilized in the present study were acquired by Golitko during several collecting trips in late 2010. This included field collections of source samples from sources in northern Arizona and New Mexico. These SW samples were supplemented by materials acquired by the Field Museum from Jeffrey Fergusson (University of Missouri), comprising a far larger set of source samples for Arizona and New Mexico. These two sample sets represent all the commonly identified source materials utilized in the US Southwest in the past and all those that have been identified at archaeological sites on the central and southern Plains (e.g., Jones *et al.* 2019). Wyoming and Idaho source samples were acquired from Richard Holmer (Idaho State University), and include Obsidian Cliff and the primary southern Idaho sources (see Figure 3.2). Unfortunately, it was not possible to acquire source material from other sources located in Yellowstone National Park or from Teton Pass and other Wyoming sources. To the extent possible, we compared published data (Bohn 2007; Griffin *et al.* 1969; Hughes 1995; Nelson 1984) for these sources to our new measurements.

PXRF analyses

PXRF analyses were carried out in two phases. A pilot study was conducted during November 2010 as an initial assessment of whether PXRF was capable of separating relevant source samples and assigning artifacts to those sources, but including only Idaho and Wyoming source samples. That study utilized an Innov-X alpha PXRF housed at the Field Museum Elemental Analysis Facility (EAF) using the instrument's 'soils' Fundamental Parameter mode along with 'light element analysis' to generate compositional data for ten elements (K, Ca, Ti, Mn, Fe, Zn, Rb, Sr, Zr, and Nb—see Feinman *et al.* 2013 for a full description of instrumentation and quantification). Source assignments for objects in accession FM56774 are based on these initial results as these objects were inadvertently omitted from later analysis (see Appendix 3.1).

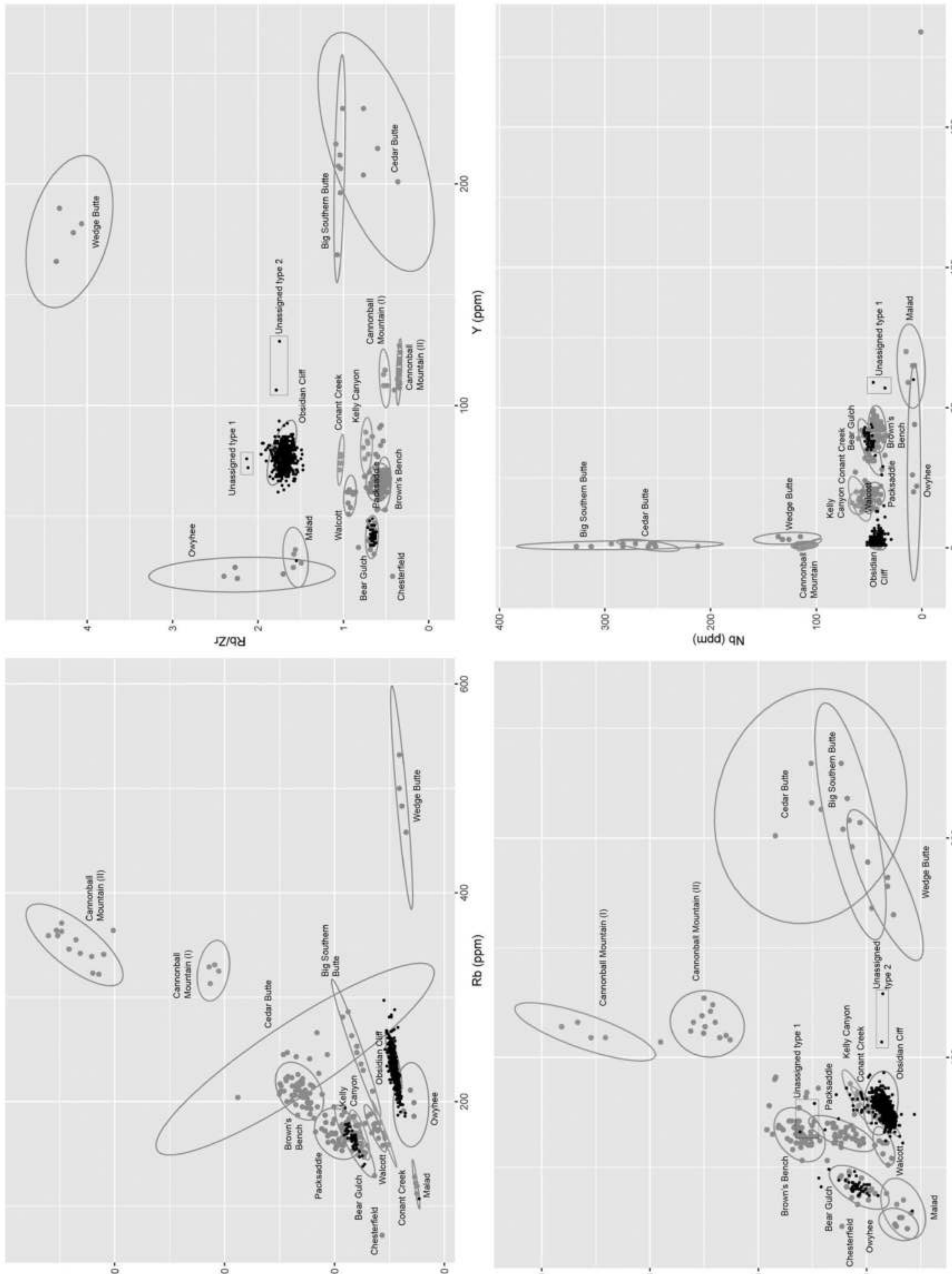

Figure 3.2. Bivariate plots showing results of obsidian sourcing compared to sources in Yellowstone National Park (Obsidian Cliff) and southern Idaho. Black dots are Hopewell objects, gray dots are obsidian raw material samples. Ellipses indicate 95% confidence intervals around source samples.

All other samples were analyzed by Stanecki during July and August of 2019 using a Bruker Tracer 5i PXRF from the Notre Dame Archaeological X-ray Facility (NDAXL). Concentrations were generated using the empirical calibration provided by Bruker based on the 'MURR2" set of 40 solid obsidian samples (Speakman 2012). This calibration uses a 40 keV beam energy and 32µA current to generate peak heights for ten elements (Mn, Fe, Zn, Ga, Rb, Sr, Y, Zr, Nb, and Th). A solid obsidian piece (BRK001) was run before and after each day's analyses, as were rhyolitic certified reference materials USGS RGM-2 and NIST278 (prepared as pressed pellets). Results of these repeat analyses are presented in Table 3.1 X-ray counts were collected for 30s per measurement. For larger bifaces, three measurements were taken at different spots (avoiding paint and filler material) and averaged, while smaller debitage pieces were measured once. All raw material samples were also measured using the Tracer 5i for comparison to archaeological pieces.

Results

Source Assignments

Hopewell obsidian was compared to raw material samples through both inspection of bivariate plots and posterior classification by canonical discriminant function analysis (CDA) with all measured obsidian sources included as input groups. CDA was carried out in the MASS package within the R programming environment. Measured Zn concentrations varied over several orders of magnitude in archaeological samples in both the 2010 pilot study and in the 2019 analyses. At present, it is not clear why these anomalously high values were present in some pieces but not others (but could plausibly represent accidental analysis of paint, labelling ink, or filler material), but Zn concentrations were omitted from statistical analyses as a result. The CDA produces 100% posterior classification success for southern Idaho and Yellowstone sources, and an overall posterior classification rate of 86.3% for raw material samples. Mismatches represent a handful of misclassifications between geographically proximate and geochemically similar sources in the Southwest (for instance, sources within the Mt. Taylor volcanic region of northern New Mexico). In other words, it is highly unlikely that archaeological objects would be misclassified as originating from a source in the Southwest when they actually originated from sources in Wyoming or Idaho. It is also highly unlikely obsidian from one source in Idaho or Wyoming would be miss-assigned to another source flow within that region.

As in prior studies of obsidian from Middle Woodland contexts, none of the material analyzed in this study can be associated with source flows in the US Southwest—when all measured source materials were included in the CDA, no Hopewell obsidian sample has any significant probability of associating with any measured source in Arizona or New Mexico. Unsurprisingly, the vast majority of material can be confidently assigned to either the Obsidian Cliff or Bear Gulch/Camas Dry Creek source flows (Figure 3.2). However, one piece of angular debitage included in lot FM970390 is a clear match for the Malad source flow and represents the first identification of this material at the Hopewell site. Four other samples remain unassigned, but group as pairs with similar concentration profiles, termed unassigned types 1 and 2 for the time being. While similar to Obsidian Cliff samples on other elements, unassigned type 1 samples (FM970390a121 and FM970397c) have elevated Fe concentrations but are principally distinguished by much higher Sr concentrations (57–59 ppm) than are found in glass from Obsidian Cliff (c. 2–12 ppm). Sr values in the Teton Pass/Fish Creek source flow are considerably higher (c. 120 ppm) making a derivation from this source highly unlikely. These 'type 1' unknown samples have compositions consistent with published values for the Park Point source in Yellowstone (Bohn 2007; McIntyre *et al.* 2013), but comparison with source samples measured on the same instrument would be needed to confirm this assignment. Unknown 'type 2' samples (FM 970390a86 and FM970399i) differ from Obsidian Cliff samples due to elevated Ga, Y, and Th concentrations. Possibly, these samples could derive from other source flows within the Yellowstone Caldera not included in the present study (e.g., MacDonald *et al.* 2019), or could represent the outer limits of concentrations found within the Obsidian Cliff source. As we have measured only five source samples from Obsidian Cliff, it is possible that our analysis does not capture the full range of elemental variability present in Obsidian Cliff glass.

Source representation by morphological categories

Viewed by morphological type (Table 3.2), our results indicate that c. 77% of bifaces at the Hopewell site were made on Obsidian Cliff obsidian, while c. 22% are of Bear Gulch obsidian. These numbers should be treated as approximate both because some fragmented bifaces may come from the same pieces but are treated as separate in this tally, and also because a number of bifaces from the site are currently housed at other institutions (e.g., material from Mound 9 at the British Museum). That said, this percentage breakdown appears consistent with those found in earlier studies, as well as a recent PXRF study of four bifaces from Hopewell housed at the Milwaukee Public Museum, which attributed three further bifaces to Obsidian Cliff and one further biface to Bear Gulch (Schmitz 2020). All 'triangular bottom' Ross Knives in

Table 3.1. Results of repeat (60 replicates) analyses on solid obsidian sample BRK001 and certified reference materials RGM-2 and NIST278.

		Mn	Fe	Zn	Ga	Rb	Sr	Y	Zr	Nb	Th
BRK001	ppm	413	6158	49	17	263	6	56	83	30	27
	%RSD	7%	3%	9%	14%	3%	12%	5%	6%	7%	8%
USGS RGM-2	ppm	259	12293	38	11	142	96	21	193	7	13
	%RSD	10%	4%	11%	21%	5%	4%	9%	4%	20%	13%
certified	ppm	273	13000	33	15	147	108	24	222	9	15
NIST278	ppm	351	13396	52	14	123	56	39	238	14	11
	%RSD	9%	8%	8%	17%	15%	12%	8%	9%	21%	25%
certified	ppm	402	14279	55		127.5	63.5				12.4

Table 3.2. Source assignments by object category.

Category	Obsidian Cliff	Bear Gulch	Malad	Unassigned "type 1"	Unassigned "type 2"	Total
Bifaces	*77.2% (115)*	*21.5% (32)*		*0.7% (1)*	*0.7% (1)*	*149*
Ross Knives	75.5% (34)	24.4% (11)				45
Triangular bottom Ross Knives	100% (11)					11
Atypical Ross Knives		100% (1)				1
Ovoid Knives	80% (4)	20% (1)				5
Ross Points	90% (18)	10% (2)				20
Ovoid Points	63.6% (7)	36.4% (4)				11
Lancelet Points		100% (3)				3
Flat-based Points	100% (3)					3
Point fragments	76.5% (13)	17.6% (3)		5.9% (1)		17
Biface fragments	75.8% (25)	21.2% (7)			3% (1)	33
Bladelets and Bladelet Cores	*100% (6)*					*6*
Bladelets	100% (3)					3
Bladelet Cores	100% (3)					3
Debitage	*95.7% (377)*	*3.6% (14)*	*0.3% (1)*	*0.3% (1)*	*0.3% (1)*	*394*
Angular Debitage	93.1% (217)	6% (14)	0.4% (1)		0.4% (1)	233
Flakes	99.4% (158)			0.6% (1)		159
Flake Cores	100% (2)					2
Total	90.7% (498)	8.4% (46)	0.2% (1)	0.4% (2)	0.4% (2)	549

the Field collections—those from which the bottom tangs appear to have been deliberately removed—were sourced to Obsidian Cliff, while a single 'atypical' Ross Knife (FM56777, see Greber and Ruhl 1989: Figure 6.5b)—in this case with a strongly curved blade and unusual tang orientation—was produced on Bear Gulch obsidian. Ovoid knives appear to roughly mimic the overall representation of source materials, with some 80% produced on Obsidian Cliff material and the other 20% on Bear Gulch.

Smaller bifacial points follow roughly the same pattern, although Ross tanged points are slightly more likely to be produced on Obsidian Cliff material (c. 90%) than Bear Gulch (c. 10%). Ovoid points and ovoid points with fishtail bases are slightly more frequently made on Bear Gulch material (c. 36%) than other biface categories. All flat-based points are made of Obsidian Cliff glass, while all points categorized as 'Lancelet' are made on Bear Gulch obsidian. However, given the sample sizes for these categories, it is questionable as to whether this patterning is real or reflects sample size. Point and biface fragments follow the overall frequency trends closely—some 75–76% are of Obsidian Cliff glass, and c. 20% Bear Gulch. As such, there does not appear to be any systematic differences in which source flow different types of bifaces were produced from that might imply production at different places or within marginally variant stylistic traditions.

Other morphological types within the Hopewell obsidian assemblage do not appear to follow the percentage breakdown of source frequencies present amongst bifaces at the site. The bladelets and bladelet cores in lot FM56554 (Mound 25) and FM970390 (unknown provenience) are all on Obsidian Cliff glass. Amongst pieces categorized as either angular debitage or flakes, more than 90% consist of Obsidian Cliff material, but when considering only flakes, all material was assigned to either Obsidian Cliff or one of the unassigned source types. Bear Gulch and Malad are only present amongst the angular debitage.

Discussion

To summarize, our new results, based on a nearly comprehensive source characterization of the Field Museum Hopewell collection indicate that slightly more than three quarters of the bifaces present in the Field Museum Hopewell collections were produced on Obsidian Cliff obsidian. These results are consistent with prior studies and suggest that this ratio of Obsidian Cliff to other sources is likely approximately representative of the entire site assemblage (e.g., Hughes 2006: Table 20.1). All other bifaces or identifiable biface fragments analyzed here were produced on Bear Gulch obsidian. Volcanic glass from the Malad source in southeastern Idaho is present at the Hopewell site, although on present evidence, at very low frequencies. This finding is one of only a handful of pieces of Malad obsidian from a Middle Woodland context (excepting the possibility that it is associated with Late Woodland occupation at Hopewell)—at present, the only piece with a clear Middle Woodland association is from the Baehr-Gust site in Illinois (Hughes 2006), although two flakes have been identified in potential Middle Woodland contexts in Minnesota (Hughes 2007) and in later contexts in Arkansas at the Brown Bluff Site (Hughes *et al.* 2002). The Malad piece at Hopewell (FM970390a67) is included in the 'angular debitage' category, and could therefore have hypothetically come from a shattered biface, however, this piece could just as well be an isolated find of this material, as is the case at other sites where Malad has been identified.

Based both on results presented here, and on prior studies of Middle Woodland obsidian, it is clear that the 'one shot' hypothesis is unlikely to account for entirety of obsidian acquisition within the broader Hopewell 'interaction sphere,' and indeed, to an extent this model appears to have turned into a strawman argument in its 'pure' form. That said, available data do not entirely rule out the possibility that the vast majority of volcanic glass from the Obsidian Cliff source specifically could have been acquired as part of a single procurement event, either by residents of the Scioto area, or by travelers from the Yellowstone area. It is also clear that Obsidian Cliff material reached east of the Mississippi both before and after the Middle Woodland periods, so any such voyages likely implicate preexisting social connections spanning large areas of North America, even if the volume of material that was moved was far lower than during the Middle Woodland period. While DeBoer (2004) has suggested a northerly route for Obsidian Cliff glass down through the Great Lakes, available distributional data are also consistent with travel down the Missouri to the Mississippi and Ohio, with limited subsequent movement of obsidian outwards from Hopewell further northwards.

While the distribution of Bear Gulch/Camas Dry Creek obsidian likewise could be accounted for by movement along the Missouri through similar pathways as Obsidian Cliff glass, it seems likely that this material, along with Malad and Teton Pass obsidians, was primarily transported further southwards along the Platt River before entering the Mississippi and Ohio River Valleys. Our new results largely confirm the earlier results of Hughes (2006), who also analyzed debitage from Mounds 11 and 17 not included in our study—there is no conclusive evidence for production waste on a material other than Obsidian Cliff glass in the Hopewell assemblage. All flakes, flake cores, bladelets, and bladelet cores analyzed come from Obsidian Cliff, while Bear Gulch and Malad are present only as bifaces, biface fragments, or angular debitage that may have originally been part of bifaces. There is a single flake made on one of the unassigned source types (FM970390a121)—this is the high-Sr unidentified source, and at least plausibly could therefore represent production waste of material other than Obsidian Cliff. As such, our results lend further support to Hughes' (2006) argument for transport of Bear Gulch bifaces as finished implements to Hopewell from elsewhere. If so, it is worth pondering the social motivations for this second route of obsidian transport and production, although interpretations may vary depending on which model of Middle Woodland society one prefers. For instance, treating the Hopewell site as the scene of competitive feasts pitting political elites against each other might suggest that Bear Gulch obsidian was brought to the site by individuals or polities that had been excluded from acquisition of Obsidian Cliff material. Alternatively, if viewed as a meeting point linking low density and mobile communities together, acquisition of obsidian from multiple sources via multiple social and geographic pathways might reflect reverential offerings brought to a cosmologically and/or ritually significant place on the landscape during certain times of the year by people who otherwise largely engaged in separate segments of the broader Hopewell social world.

While there are intrinsic limitations to the Hopewell assemblage owing to the nature of the excavations carried out there and subsequent destruction of much of the site, future work may still allow for further understanding of how (and why) obsidian and other widely transported materials came to the site in such quantities. It is unclear what percentage of the total obsidian present at Hopewell is represented in extant collections—further material may still be present in sub-surface deposits, or may have been removed by plowing and other agricultural activities. Even without further fieldwork, future PXRF studies of the remaining debitage from Mound 11 (more than 10,000 individual pieces) could be undertaken to determine whether production debris from sources other than Obsidian Cliff is present or not. Hatch and colleagues (1990) also question whether flake debitage at the site was associated with production of bifaces or with some other end product. A formal analysis of the material is warranted to assess their claim and determine whether or not the materials we classify as angular debitage are entirely pieces of fragmented bifaces or also include some waste associated with other types of tool production. In conjunction with refitting, such an analysis might shed considerable light on how obsidian entered and possibly left the Hopewell site.

Conclusions

This study presents a substantial increase in the total volume of sourced obsidian from the Hopewell site, primarily through the addition of biface fragments and debitage included in Field Museum accessions that had not been previously analyzed. In common with earlier sourcing studies of obsidian from Hopewell, we find that between 75–90% of all obsidian present can be assigned to the Obsidian Cliff source in Yellowstone National Park. Most of the remaining material comes from the Bear Gulch/Camas Dry Creek source in eastern Idaho. Our study also identified a single piece of Malad obsidian from southeastern Idaho as well as two potential compositional profiles that might reflect additional sources. If these are indeed sources beyond the three we have conclusively identified, their likeliest origin point would be within the Yellowstone Caldera, where there are a number of additional minor source flows. As in earlier studies, we find no evidence for production waste on sources other than Obsidian Cliff, lending further support to Hughes' (2006) argument that Bear Gulch obsidian arrived at Hopewell in the form of finished bifaces rather than as raw blocks or cores. It remains unclear how Malad obsidian arrived at Hopewell, but the single piece we identified may be a fragment of a biface, suggesting the possibility that this material also was first transported elsewhere before being worked and then transported to Hopewell. Our results further suggest that Griffin's (1965) 'one shot' hypothesis for obsidian transport into the Hopewell Interaction Sphere is unlikely to account for all of the obsidian found in Middle Woodland assemblages, but remains plausible for Obsidian Cliff glass.

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Appendix 3.1

PXRF measurements (including the instrument used) listed by Field Museum inventory number and morphological classification and description. Provenience information is provided when available.

ID	Prov	Sub.prov	Type	Description	Instrument	Source	K	Ca	Ti	Mn	Fe	Zn	Ga	Rb	Sr	Y	Zr	Nb	Th	Ba	Pb
FM110149a	Mound 11		flake	debitage	Bruker Tracer 5i	Obsidian Cliff				210	8324	88	19	232	2	83	139	44	28		
FM110149b	Mound 11		flake	debitage	Bruker Tracer 5i	Obsidian Cliff				163	8502	98	15	238	3	75	143	44	27		
FM56504-118	Mound 25	Altar 1	Ross Knife	biface knife proximal	Bruker Tracer 5i	Obsidian Cliff				144	8164	256	14	220	4	71	129	40	27		
FM56504-118a	Mound 25	Altar 1	Ross Knife	biface knife medial fragment	Bruker Tracer 5i	Obsidian Cliff				128	8444	95	10	220		70	127	36	25		
FM56504-118b	Mound 25	Altar 1	Biface	biface fragment	Bruker Tracer 5i	Bear Gulch				256	9753	54	12	140	33	37	218	44	19		
FM56504-118c	Mound 25	Altar 1	Ovoid Point	biface point medial fragment	Bruker Tracer 5i	Obsidian Cliff				184	7555	87	15	206		71	129	36	24		
FM56504-118d	Mound 25	Altar 1	Ross Knife	biface knife proximal end	Bruker Tracer 5i	Obsidian Cliff				223	8218	277	19	231		68	129	41	28		
FM56504-118e	Mound 25	Altar 1	Ross Knife	biface point distal fragment	Bruker Tracer 5i	Bear Gulch				226	10766	107	12	166	38	37	243	47	19		
FM56504-118f	Mound 25	Altar 1	Ovoid Point	biface point proximal end, fishtail base	Bruker Tracer 5i	Bear Gulch				227	10724	82	14	162	36	40	241	50	21		
FM56504a			Bladelet	Bladelet	Bruker Tracer 5i	not obsidian				47	267	10			3	4			3		
FM56504b			Bladelet	Bladelet	Bruker Tracer 5i	not obsidian				56	211	9			3	9	2		3		
FM56504c			Bladelet	Bladelet	Bruker Tracer 5i	not obsidian				93	560	74			3	8			4		
FM56504d			Flake	Flake	Bruker Tracer 5i	not obsidian				79	309	11			5	4					
FM56504e			Bladelet	Bladelet	Bruker Tracer 5i	not obsidian				114	536	14			5			3			
FM56504f			Flake	Flake	Bruker Tracer 5i	not obsidian				83	271	10			3	4					
FM56504g			Bladelet	Bladelet	Bruker Tracer 5i	not obsidian				228	2908	29		2	9		3				
FM56504h			Bladelet	Bladelet	Bruker Tracer 5i	not obsidian				91	497	55			4		2				
FM56504i			Bladelet	Bladelet	Bruker Tracer 5i	not obsidian				112	361	10			4	11			3		
FM56504j			Bladelet	Bladelet	Bruker Tracer 5i	not obsidian				74	568	10			4	8			7		
FM56504k			Bladelet	Bladelet	Bruker Tracer 5i	not obsidian				154	3111	1403	15		5	4	3	8			
FM56504l			Flake	Flake	Bruker Tracer 5i	not obsidian				75	458	11			6	8					
FM56504m			Bladelet	Bladelet	Bruker Tracer 5i	not obsidian				76	228	12			4	3	2				
FM56552.1	Mound 25	Altar 1	Ross Point	biface tanged point	Bruker Tracer 5i	Obsidian Cliff				128	8224	98	16	219	5	62	129	35	22		
FM56552.2	Mound 25	Altar 1	Ross Point	biface tanged point	Bruker Tracer 5i	Obsidian Cliff				204	5587	189	22	195	29	74	126	37	23		
FM56554.1	Mound 25	Altar 1	Bladelet Core	Bladelet Core	Bruker Tracer 5i	Obsidian Cliff				148	6941	122	13	210	3	69	122	38	24		
FM56554.3	Mound 25	Altar 1	Bladelet Core	Bladelet Core	Bruker Tracer 5i	not obsidian				66	115	41			3	5					
FM56554.4	Mound 25	Altar 1	Bladelet Core	Bladelet Core	Bruker Tracer 5i	Obsidian Cliff				163	7573	196	19	233	4	78	130	46	27		
FM56554.6	Mound 25	Altar 1	Bladelet Core	Bladelet Core	Bruker Tracer 5i	Obsidian Cliff				241	8953	249	18	234	13	80	157	42	28		
FM56768a	Village site		Angular debitage	debitage	Bruker Tracer 5i	Bear Gulch				298	10948	61	16	172	38	46	270	54	24		
FM56772a			Ross Point	biface tanged point	Bruker Tracer 5i	Obsidian Cliff				202	8085	72	23	229	2	74	138	44	26		
FM56772b			Ross Point	biface tanged point	Bruker Tracer 5i	Obsidian Cliff				181	8671	131	22	248	2	82	147	45	29		
FM56772c			Ross Point	biface tanged point	Bruker Tracer 5i	Obsidian Cliff				142	7674	183	16	217		71	131	39	25		
FM56772d			Ross Point	biface tanged point	Bruker Tracer 5i	Obsidian Cliff				273	7873	86	25	241	3	77	146	44	28		
FM56772e			Ross Point	biface tanged point, tangs removed	Bruker Tracer 5i	Obsidian Cliff				233	8276	110	23	241	3	81	134	46	29		
FM56772f			Ross Point	biface point proximal fragment	Bruker Tracer 5i	Obsidian Cliff				203	8585	85	24	247	2	84	148	43	28		
FM56773a	Mound 25	Altar 1 or 2	Ross Knife	biface knife	Bruker Tracer 5i	Obsidian Cliff				133	7832	143	10	199	5	67	127	37	24		

ID	Prov	Sub.prov	Type	Description	Instrument	Source	K	Ca	Ti	Mn	Fe	Zn	Ga	Rb	Sr	Y	Zr	Nb	Th	Ba	Pb
FM56773b	Mound 25	Altar 1 or 2	Ross Point	biface tanged point	Bruker Tracer 5i	Obsidian Cliff				218	8486	185	23	235	6	87	146	45	32		
FM56773c	Mound 25	Altar 1 or 2	Ross Point	biface tanged point	Bruker Tracer 5i	Obsidian Cliff				187	8326	178	17	232	7	75	132	41	29		
FM56773e	Mound 25	Altar 1 or 2	Ross Point	biface tanged point	Bruker Tracer 5i	Obsidian Cliff				204	7868	102	21	234	2	76	139	45	27		
FM56773f	Mound 25	Altar 1 or 2	Ross Point	biface tanged point	Bruker Tracer 5i	Obsidian Cliff				317	7620	139	24	234	6	76	141	41	29		
FM56774a			Ovoid Point	Ovoid point with fishtail base	Innov-X Alpha	Obsidian Cliff	36868	6375	325	273	7890	159		236	6		159	41		277	71
FM56774b			Ovoid Point	Ovoid point with fishtail base	Innov-X Alpha	Bear Gulch	41812	7330	1382	291	10412	65		165	43		280	44		671	35
FM56774c			Ovoid Point	Ovoid point with fishtail base	Innov-X Alpha	Obsidian Cliff	37348	2461	271	184	7933	83		236	6		160	41		302	45
FM56774d			Ovoid Point	Ovoid point with fishtail base	Innov-X Alpha	Obsidian Cliff	37719	2469	292	177	7884	68		232			156	38		273	36
FM56774f			Ovoid Point	Ovoid point with fishtail base	Innov-X Alpha	Bear Gulch	40012	41180	1218	293	10251	47		159	41		268	42		753	34
FM56774g			Ovoid Point	Ovoid point with fishtail base	Innov-X Alpha	Obsidian Cliff	38759	3738	330	198	8605	85		231			156	39		267	67
FM56776			Lancelet Point	biface point	Bruker Tracer 5i	Bear Gulch				282	10469	56	15	155	35	41	240	48	20		
FM56777			Atypical Ross Knife	biface curved knife double tang	Bruker Tracer 5i	Bear Gulch				228	10640	78	10	164	38	40	242	45	19		
FM56780a	Mound 25		Flat-based Point	biface point	Bruker Tracer 5i	Obsidian Cliff				158	7769	77	14	216	2	73	128	41	24		
FM56780b	Mound 25		Flat-based Point	biface point	Bruker Tracer 5i	Obsidian Cliff				185	7610	208	14	213	6	72	126	37	26		
FM56781			Point	biface point preform?	Bruker Tracer 5i	Bear Gulch				337	10856	64	17	176	39	41	262	51	22		
FM56783			Ross Knife	biface knife proximal end	Bruker Tracer 5i	Obsidian Cliff				162	7808	84	13	217	3	72	126	40	25		
FM56785			Triangular Bottom Ross Knife	biface knife, tangs removed	Bruker Tracer 5i	Obsidian Cliff				164	7977	93	15	219	2	73	127	40	29		
FM56786			Ross Knife	biface knife proximal end	Bruker Tracer 5i	Bear Gulch				239	10877	170	10	159	40	41	239	47	20		
FM56787			Triangular Bottom Ross Knife	biface knife, tangs removed	Bruker Tracer 5i	Obsidian Cliff				92	7800	87	19	216		73	128	37	36		
FM56788			Ross Knife	biface knife (tang missing)	Bruker Tracer 5i	Obsidian Cliff				148	7934	93	11	221	4	71	137	38	27		
FM56789			Triangular Bottom Ross Knife	biface knife, tangs removed	Bruker Tracer 5i	Obsidian Cliff				179	8044	86	16	226		74	133	40	27		
FM56790			Ross Knife	biface knife	Bruker Tracer 5i	Obsidian Cliff				111	7424	81	11	205		69	125	37	26		
FM56791			Ross Knife	biface knife	Bruker Tracer 5i	Obsidian Cliff				170	8021	74	15	226		71	133	42	28		
FM56792	Mound 25		Ross Knife	biface knife	Bruker Tracer 5i	Obsidian Cliff				165	7908	129	13	218	4	71	128	38	25		
FM56793			Ross Knife	biface knife (preform?)	Bruker Tracer 5i	Obsidian Cliff				150	8435	75	16	232	3	77	141	42	30		
FM56794			Ross Knife	biface knife	Bruker Tracer 5i	Obsidian Cliff				171	7750	94	12	209	4	68	121	39	28		
FM56795			Ross Knife	biface knife	Bruker Tracer 5i	Bear Gulch				221	10287	72	11	158	36	39	241	48	21		
FM56796			Ross Knife	biface knife	Bruker Tracer 5i	Obsidian Cliff				136	7859	103	13	224	2	73	134	39	28		
FM56801	Mound 25	Altar 1	Ross Knife	biface knife	Bruker Tracer 5i	Bear Gulch				246	11005	61	11	158	37	42	246	46	21		
FM56803			Ross Knife	biface knife	Bruker Tracer 5i	Obsidian Cliff				119	8061	80	9	213		72	128	40	27		
FM56806			Ross Knife	biface knife	Bruker Tracer 5i	Obsidian Cliff				297	6658	773	15	189	5	61	107	32	26		
FM56808			Ross Knife	biface knife	Bruker Tracer 5i	Obsidian Cliff				137	7557	76	15	212	3	71	126	39	26		
FM56809			Ross Knife	biface knife (preform?)	Bruker Tracer 5i	Obsidian Cliff				154	7766	68	13	213	2	72	127	40	25		
FM56810	Mound 25		Ross Knife	biface knife	Bruker Tracer 5i	Obsidian Cliff				177	7606	832	24	187	11	73	127	35	39		
FM56811			Ross Knife	biface knife	Bruker Tracer 5i	Obsidian Cliff				146	7904	75	13	222		71	130	39	29		
FM56812			Ross Knife	biface knife	Bruker Tracer 5i	Obsidian Cliff				192	7809	212	14	213	5	71	125	39	28		
FM56813			Ross Knife	biface knife proximal and medial fragments	Bruker Tracer 5i	Obsidian Cliff				153	8583	146	19	232	2	77	134	39	29		
FM56814			Lancelet Point	biface point	Bruker Tracer 5i	Bear Gulch				215	10864	59	11	153	36	41	233	46	22		
FM56815			Ross Knife	biface knife	Bruker Tracer 5i	Obsidian Cliff				154	8625	85	15	241	2	76	140	42	26		
FM56817			Triangular Bottom Ross Knife	biface knife	Bruker Tracer 5i	Obsidian Cliff				142	8025	75	14	220	2	72	136	40	26		
FM56818			Ross Knife	biface knife (preform?)	Bruker Tracer 5i	Obsidian Cliff				154	8530	73	16	230	3	77	133	43	29		

ID	Prov	Sub.prov	Type	Description	Instrument	Source	K	Ca	Ti	Mn	Fe	Zn	Ga	Rb	Sr	Y	Zr	Nb	Th	Ba	Pb
FM56822			Triangular Bottom Ross Knife	biface knife	Bruker Tracer 5i	Obsidian Cliff				149	7681	76	14	219	2	73	131	40	27		
FM56823			Triangular Bottom Ross Knife	biface knife	Bruker Tracer 5i	Obsidian Cliff				106	7596	69	10	206	2	69	122	36	23		
FM56824			Triangular Bottom Ross Knife	biface knife	Bruker Tracer 5i	Obsidian Cliff				125	8115	81	16	226	3	73	130	41	27		
FM56825			Ovoid Knife	biface knife	Bruker Tracer 5i	Bear Gulch				235	11946	64	10	172	40	44	262	50	23		
FM56826			Triangular Bottom Ross Knife	biface knife	Bruker Tracer 5i	Obsidian Cliff				173	8331	79	16	231		77	139	41	26		
FM56828			Ovoid Knife	biface knife	Bruker Tracer 5i	Obsidian Cliff				168	7876	80	14	214	3	71	128	35	26		
FM56829			Ovoid Knife	biface knife	Bruker Tracer 5i	Obsidian Cliff				151	8381	79	14	237	3	74	136	44	27		
FM56830.1			Ovoid Point	biface point	Bruker Tracer 5i	Obsidian Cliff				169	8324	84	14	230		77	139	44	27		
FM56830.2			Ovoid Knife	drilled biface fragment	Bruker Tracer 5i	Obsidian Cliff				224	7941	82	22	239	3	76	139	43	28		
FM56831			Ross Knife	biface knife	Bruker Tracer 5i	Obsidian Cliff				157	7838	79	25	222	3	78	132	40	36		
FM56833			Ovoid Knife	biface knife	Bruker Tracer 5i	Obsidian Cliff				235	8896	96	19	245	3	79	143	46	30		
FM56835			Ovoid Point	biface knife	Bruker Tracer 5i	Obsidian Cliff				161	7466	167	17	215		73	131	40	27		
FM56867			Ross Knife	biface knife	Bruker Tracer 5i	Bear Gulch				216	11288	72	9	162	39	39	243	51	19		
FM970388			Ross Point	biface point fragment	Bruker Tracer 5i	Bear Gulch				262	11310	62	13	165	41	41	264	53	21		
FM970389			Ovoid Point	biface distal fragment (preform?)	Bruker Tracer 5i	Bear Gulch				247	11339	111	10	159	35	39	242	52	20		
FM970390a			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				214	9165	82	23	257		78	150	47	30		
FM970390a1			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				210	8303	72	19	235	2	75	132	42	26		
FM970390a10			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				224	8012	74	21	229	2	74	132	44	30		
FM970390a100			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				187	9216	81	20	249		81	142	48	32		
FM970390a101			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				211	8402	100	25	239	4	74	133	44	31		
FM970390a102			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				175	7301	68	19	220		74	131	40	26		
FM970390a103			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				136	8548	78	15	236		71	136	41	25		
FM970390a104			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				157	8043	80	41	236	3	81	147	38	43		
FM970390a105			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				198	8229	82	19	241	2	79	138	46	30		
FM970390a106			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				285	9129	83	22	245		78	143	44	29		
FM970390a107			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				169	7861	86	20	226	2	72	132	39	27		
FM970390a108			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				245	8922	75	19	236	2	76	147	42	29		
FM970390a109			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				190	8351	107	19	229		74	139	43	32		
FM970390a11			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				209	9106	83	17	255		82	148	45	30		
FM970390a110			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				256	8813	83	45	259	2	89	147	44	45		
FM970390a111			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				196	7340	86	17	212	2	70	130	38	21		
FM970390a112			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				184	8035	79	18	228	2	75	135	42	30		
FM970390a113			Bladelet	bladelet	Bruker Tracer 5i	Obsidian Cliff				169	9083	76	21	260	2	86	148	45	27		
FM970390a114			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				250	8589	84	24	247	3	81	145	44	30		
FM970390a115			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				193	8358	77	22	236		76	137	43	29		
FM970390a116			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				264	8092	77	31	235		76	139	48	26		
FM970390a117			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				145	8722	108	15	232		77	145	42	26		
FM970390a118			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				209	16148	79	18	237	4	66	142	43	27		
FM970390a119			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				206	7943	73	23	228	3	78	134	41	23		
FM970390a12			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				164	8739	81	18	250	3	82	153	43	27		
FM970390a120			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				196	8917	84	22	240		76	136	40	27		
FM970390a121			Flake	debitage	Bruker Tracer 5i	unassigned 1				459	13834	176	15	199	57	67	126	35	24		
FM970390a122			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				195	10866	120	18	271		76	127	38	29		

ID	Prov	Sub.prov	Type	Description	Instrument	Source	K	Ca	Ti	Mn	Fe	Zn	Ga	Rb	Sr	Y	Zr	Nb	Th	Ba	Pb
FM970390a123			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				163	9413	88	25	263		77	151	48	32		
FM970390a124			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				142	8203	101	12	234	7	71	138	39	26		
FM970390a125			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				173	7903	77	22	233		79	137	44	28		
FM970390a126			Bladelet	Bladelet	Bruker Tracer 5i	Obsidian Cliff				177	8924	89	23	244	3	81	142	42	31		
FM970390a127			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				206	9890	97	24	255		78	139	46	32		
FM970390a128			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				233	9141	78	19	234	3	77	148	41	26		
FM970390a129			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				220	14811	138	22	250	4	79	152	47	28		
FM970390a13			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				279	9994	97	23	246	3	81	144	44	29		
FM970390a130			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				123	7477	84	15	222		71	129	39	23		
FM970390a131			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				250	7958	109	24	224	2	77	139	41	26		
FM970390a132			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				158	7517	66	20	221	3	71	134	46	25		
FM970390a133			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				201	8026	89	18	233		78	142	40	27		
FM970390a134			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				170	9060	75	19	251		82	146	46	30		
FM970390a135			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				197	12594	115	24	288	4	72	136	40	37		
FM970390a136			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				180	9248	92	22	255		77	143	41	32		
FM970390a137			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				178	11245	115	19	269	3	78	137	39	33		
FM970390a138			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				201	8683	91	19	231	3	75	135	39	26		
FM970390a139			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				229	9456	91	23	266	4	85	158	47	35		
FM970390a14			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				209	8485	81	23	239		79	145	43	28		
FM970390a140			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				238	8786	83	34	234	3	78	140	40	35		
FM970390a141			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				289	9540	82	20	258	2	80	135	44	30		
FM970390a142			Angular debitage	debitage	Bruker Tracer 5i	not obsidian				107	517	17									
FM970390a143			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				156	8275	87	22	236		77	142	45	26		
FM970390a144			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				173	8102	75	24	225		71	135	40	26		
FM970390a145			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				140	7683	72	15	205		68	117	37	24		
FM970390a146			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				220	9388	91	23	251		77	140	42	29		
FM970390a147			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				202	9369	111	18	244	4	81	141	41	32		
FM970390a148			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				206	7845	71	16	220		70	135	41	25		
FM970390a149			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				188	7989	80	19	232	2	78	141	44	27		
FM970390a15			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				136	7967	75	21	222		76	142	41	28		
FM970390a150			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				226	7832	70	18	222	2	74	127	43	25		
FM970390a151			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				183	9129	79	19	256	2	83	142	49	31		
FM970390a152			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				163	7830	84	15	207		74	126	41	29		
FM970390a153			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				192	12805	106	16	283	3	83	145	45	39		
FM970390a154			Angular debitage	debitage	Bruker Tracer 5i	Bear Gulch				264	14416	78	15	194	44	45	271	48	24		
FM970390a155			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				188	7800	82	14	229	2	76	138	44	26		
FM970390a156			Angular debitage	debitage	Bruker Tracer 5i	Bear Gulch				319	11115	62	18	171	38	42	262	50	23		
FM970390a157			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				191	8290	88	20	236		75	131	41	31		
FM970390a158			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				185	8718	75	20	238	2	77	138	40	27		
FM970390a159			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				204	7621	97	76	226	3	83	130	39	63		
FM970390a16			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				211	8258	75	18	229		70	132	45	26		
FM970390a160			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				188	8549	97	24	245	3	77	142	43	31		

ID	Prov	Sub.prov	Type	Description	Instrument	Source	K	Ca	Ti	Mn	Fe	Zn	Ga	Rb	Sr	Y	Zr	Nb	Th	Ba	Pb
FM970390a161			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				187	8477	78	15	227		71	125	46	35		
FM970390a162			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				162	8614	87	16	242	3	81	144	45	28		
FM970390a163			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				203	9550	89	24	260	3	80	143	41	32		
FM970390a164			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				168	8390	88	56	252		83	141	46	45		
FM970390a165			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				227	8300	234	24	243	4	77	141	45	26		
FM970390a166			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				300	9160	208	21	220	8	74	132	41	29		
FM970390a167			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				259	8211	90	34	238	2	78	138	43	35		
FM970390a168			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				173	8620	80	20	233	2	78	135	41	27		
FM970390a169			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				179	8336	92	15	217		77	129	41	26		
FM970390a17			Angular debitage	debitage	Bruker Tracer 5i	not obsidian				722	3008	133		7	220	6	32				
FM970390a170			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				184	7871	72	26	230		71	131	44	31		
FM970390a171			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				211	8021	83	12	214	2	69	135	41	26		
FM970390a172			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				215	9484	77	15	261	3	82	154	49	30		
FM970390a173			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				261	10427	103	18	248	3	76	149	45	27		
FM970390a174			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				134	7824	79	14	224		72	131	36	26		
FM970390a175			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				154	9153	87	15	246	3	80	142	47	31		
FM970390a176			Angular debitage	debitage	Bruker Tracer 5i	Bear Gulch				228	8942	58	10	148	35	37	224	48	19		
FM970390a177			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				213	11863	105	35	297		86	165	42	48		
FM970390a178			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				165	9443	95	13	242	2	84	140	43	30		
FM970390a179			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				168	9224	84	15	243		79	142	47	30		
FM970390a18			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				203	8447	79	25	232	2	76	137	44	30		
FM970390a180			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				218	9299	87	19	253		82	135	41	31		
FM970390a181			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				172	7933	65	17	212	2	71	126	41	29		
FM970390a182			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				220	10480	108	10	265		83	154	47	32		
FM970390a183			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				205	9530	96	48	251	5	86	147	41	51		
FM970390a184			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				162	9694	91	12	255	4	92	154	44	31		
FM970390a185			Bladelet	Bladelet	Bruker Tracer 5i	Obsidian Cliff				121	10435	111	11	281		82	151	52	33		
FM970390a186			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				166	8287	72	18	248		72	143	44	31		
FM970390a187			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				219	8808	93	21	243		78	143	43	29		
FM970390a188			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				223	8410	79	111	249		93	142	45	78		
FM970390a189			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				268	8740	79	18	222	5	72	124	39	27		
FM970390a19			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				215	8354	78	20	240	2	78	136	45	28		
FM970390a190			Angular debitage	debitage	Bruker Tracer 5i	Bear Gulch				317	14203	293	10	162	43	41	253	47	23		
FM970390a191			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				183	7915	81	18	222	6	76	133	44	26		
FM970390a192			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				195	9301	109	18	249	2	78	140	41	29		
FM970390a193			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				187	10469	95	18	261		75	137	41	32		
FM970390a194			Angular debitage	debitage	Bruker Tracer 5i	not obsidian				346	89111	357			369		50				
FM970390a195			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				207	8352	93	28	222	2	76	124	41	31		
FM970390a196			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				173	8812	90	22	246	2	81	147	44	30		
FM970390a197			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				171	11284	99	19	268		81	142	43	42		
FM970390a198			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				162	8784	91	18	238	4	85	150	45	31		
FM970390a199			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				165	8458	79	21	231		77	133	44	30		

ID	Prov	Sub.prov	Type	Description	Instrument	Source	K	Ca	Ti	Mn	Fe	Zn	Ga	Rb	Sr	Y	Zr	Nb	Th	Ba	Pb
FM970390a2			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				251	8338	78	24	239	3	81	145	44	27		
FM970390a20			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				186	8265	85	37	237		86	141	46	35		
FM970390a200			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				182	7885	79	21	239		76	141	41	27		
FM970390a201			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				194	7966	74	33	224	2	78	133	41	32		
FM970390a202			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				188	8262	84	20	232	2	74	139	44	28		
FM970390a203			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				152	8408	76	22	231	2	79	136	43	25		
FM970390a204			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				190	7902	86	22	223	3	76	137	42	31		
FM970390a205			Angular debitage	debitage	Bruker Tracer 5i	not obsidian				490	5091	1421	7		139		25	6			
FM970390a206			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				150	7882	70	13	223		75	133	43	23		
FM970390a207			Angular debitage	debitage	Bruker Tracer 5i	not obsidian				76	508	49									
FM970390a208			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				157	8387	86	16	219	2	78	127	40	30		
FM970390a209			Angular debitage	debitage	Bruker Tracer 5i	Bear Gulch				279	9735	63	14	154	37	42	244	52	21		
FM970390a21			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				177	7477	68	15	220		73	133	41	29		
FM970390a210			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				117	6782	70	10	203	3	74	125	40	26		
FM970390a211			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				175	7904	75	16	236	2	82	143	50	28		
FM970390a212			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				203	7928	79	19	225		68	121	40	24		
FM970390a213			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				184	7824	101	15	208		64	121	35	25		
FM970390a214			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				240	7936	72	21	229		72	134	41	26		
FM970390a215			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				162	8267	76	25	237	3	74	136	42	28		
FM970390a216			Ross Point	biface knife fragment	Bruker Tracer 5i	Obsidian Cliff				236	8512	139	21	248	2	78	142	43	30		
FM970390a217			Ross Knife	biface fragment	Bruker Tracer 5i	Bear Gulch				288	10609	645	16	138	37	38	223	48	23		
FM970390a218			Ross Knife	biface fragment	Bruker Tracer 5i	Obsidian Cliff				292	8240	321	21	211	8	70	133	41	28		
FM970390a219			Ross Knife	biface knife proximal fragment	Bruker Tracer 5i	Obsidian Cliff				314	9924	357	17	237	7	78	140	45	27		
FM970390a22			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				199	8606	67	22	238		72	138	45	26		
FM970390a220			Lancelet Point	biface point	Bruker Tracer 5i	Bear Gulch				292	11006	87	15	164	40	41	254	51	22		
FM970390a23			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				217	8946	97	22	247	4	81	144	47	29		
FM970390a24			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				215	8566	76	26	242	2	80	140	41	28		
FM970390a25			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				173	7302	75	18	218	3	72	126	39	23		
FM970390a26			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				217	8770	83	21	254		80	149	45	30		
FM970390a27			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				189	7747	81	20	224	2	78	134	41	28		
FM970390a28			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				253	8420	83	26	237	3	81	148	45	33		
FM970390a29			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				142	7212	66	17	216		73	132	44	26		
FM970390a3			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				197	8329	78	19	235	2	78	140	42	29		
FM970390a30			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				217	8411	85	19	228	2	76	144	42	30		
FM970390a31			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				187	8397	91	15	229	3	78	136	44	25		
FM970390a32			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				200	9483	96	19	261		78	147	46	28		
FM970390a33			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				192	8304	75	25	231	3	77	148	38	30		
FM970390a34			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				189	8131	83	18	240	3	77	138	43	27		
FM970390a35			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				186	8039	79	21	236		82	149	43	28		
FM970390a36			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				161	8828	88	20	253	2	79	147	43	32		
FM970390a37			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				206	8899	91	18	239	3	77	132	46	29		

ID	Prov	Sub.prov	Type	Description	Instrument	Source	K	Ca	Ti	Mn	Fe	Zn	Ga	Rb	Sr	Y	Zr	Nb	Th	Ba	Pb
FM970390a38			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				220	8697	87	24	235	2	81	138	42	30		
FM970390a39			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				217	8731	71	25	255	2	80	148	48	31		
FM970390a4			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				204	8344	68	19	228	2	78	135	46	25		
FM970390a40			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				291	8804	327	22	238	3	76	145	44	27		
FM970390a41			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				159	9111	94	19	252	3	80	144	46	31		
FM970390a42			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				220	8254	86	21	240	3	77	142	44	28		
FM970390a43			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				190	7289	75	20	209		73	128	38	24		
FM970390a44			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				176	8324	78	27	237		76	151	47	34		
FM970390a45			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				218	8754	83	24	239	2	78	141	42	29		
FM970390a46			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				182	8082	82	22	235	3	70	136	39	29		
FM970390a47			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				267	7925	80	22	226	2	71	135	41	28		
FM970390a48			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				237	7968	70	17	234	2	77	142	40	29		
FM970390a49			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				246	8371	65	20	234		80	141	49	25		
FM970390a5			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				196	7426	75	21	217		73	132	39	25		
FM970390a50			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				198	8038	87	22	224		77	130	43	27		
FM970390a51			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				225	8258	86	27	230	3	74	136	40	25		
FM970390a52			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				186	8657	83	22	244	2	72	138	38	31		
FM970390a53			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				215	8686	88	20	236	3	79	137	41	35		
FM970390a54			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				234	8301	75	23	234	2	77	138	45	28		
FM970390a55			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				210	8363	74	14	227		72	129	40	30		
FM970390a56			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				242	7945	78	24	239	3	74	139	44	27		
FM970390a57			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				197	7978	80	19	234		86	146	40	28		
FM970390a58			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				162	9016	85	17	241	2	79	136	43	27		
FM970390a59			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				257	8514	85	18	224		75	136	42	23		
FM970390a6			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				157	7953	77	22	224	3	80	139	42	27		
FM970390a60			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				268	9396	87	16	244	3	75	139	43	28		
FM970390a61			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				168	7450	73	19	218	2	75	137	46	29		
FM970390a62			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				203	8561	77	22	243		83	152	43	28		
FM970390a63			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				173	8726	74	22	248		77	149	45	29		
FM970390a64			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				235	8150	79	23	238	3	80	151	44	25		
FM970390a65			Flake	debitage	Bruker Tracer 5i	not obsidian				143	3634	115			1194		155				
FM970390a66			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				211	8330	73	24	234	3	80	139	46	28		
FM970390a67			Angular debitage	debitage	Bruker Tracer 5i	Malad				172	5779	38	9	107	60	30	69	8	18		
FM970390a68			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				202	8344	86	23	247	2	82	144	44	28		
FM970390a69			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				207	8275	77	22	234	4	81	142	48	28		
FM970390a7			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				162	9241	81	15	232	3	80	133	41	26		
FM970390a70			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				179	8348	87	19	237		80	149	43	30		
FM970390a71			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				244	8043	72	23	233	2	77	141	45	29		
FM970390a72			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				160	8334	77	20	235	3	73	130	38	27		
FM970390a73			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				200	8303	84	23	237		78	142	49	28		
FM970390a74			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				213	8577	81	17	226	4	81	132	39	27		

ID	Prov	Sub.prov	Type	Description	Instrument	Source	K	Ca	Ti	Mn	Fe	Zn	Ga	Rb	Sr	Y	Zr	Nb	Th	Ba	Pb
FM970390a75			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				194	9015	97	19	249	3	86	152	43	31		
FM970390a76			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				332	8094	84	21	239	2	78	143	46	25		
FM970390a77			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				220	7797	85	23	232	3	78	137	43	25		
FM970390a78			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				231	8416	83	24	237	2	77	135	43	29		
FM970390a79			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				206	7937	76	17	228		75	135	42	29		
FM970390a8			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				195	8572	79	22	243		80	140	45	28		
FM970390a80			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				155	8905	84	14	243	3	80	131	44	31		
FM970390a81			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				195	7966	70	20	232		75	140	44	26		
FM970390a82			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				222	7741	74	27	228		77	134	43	27		
FM970390a83			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				210	9109	85	23	253	2	84	149	48	30		
FM970390a84			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				205	11543	122	20	281	3	83	145	44	32		
FM970390a85			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				266	8799	87	21	239	3	75	148	45	31		
FM970390a86			Angular debitage	debitage	Bruker Tracer 5i	unassigned 2				182	8609	96	136	259	3	107	145	43	100		
FM970390a87			Angular debitage	bladelet	Bruker Tracer 5i	Obsidian Cliff				158	9813	88	12	239		75	130	41	33		
FM970390a88			Angular debitage	debitage	Bruker Tracer 5i	Bear Gulch				225	10660	58	11	155	38	43	248	47	21		
FM970390a89			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				221	8276	83	23	237	2	67	130	37	29		
FM970390a9			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				175	7847	81	23	226		73	137	44	27		
FM970390a90			Angular debitage	debitage	Bruker Tracer 5i	Bear Gulch				303	13477	94	16	178	39	49	270	52	20		
FM970390a91			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				198	9055	85	21	248		76	136	44	27		
FM970390a92			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				151	9437	92	15	252		85	146	49	31		
FM970390a93			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				185	10182	130	15	267	4	77	146	46	32		
FM970390a94			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				226	8095	78	23	229	2	74	130	42	28		
FM970390a95			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				217	8799	81	35	247	4	83	156	49	32		
FM970390a96			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				258	8439	96	23	248	3	79	144	48	29		
FM970390a97			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				126	8324	95	22	232		75	141	41	25		
FM970390a98			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				179	7742	78	24	228	2	76	135	40	28		
FM970390a99			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				194	8651	79	28	248		79	142	44	30		
FM970390aa			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				211	8569	86	21	242		73	140	42	29		
FM970390b			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				245	8059	91	18	238	3	74	151	46	28		
FM970390bb			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				213	8772	74	22	242		85	145	45	29		
FM970390c			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				147	9282	101	14	228	5	78	135	42	32		
FM970390cc			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				199	8643	81	22	238	2	80	141	43	30		
FM970390d			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				191	8573	74	21	235	3	80	147	46	30		
FM970390dd			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				231	8450	83	25	238	2	84	150	46	31		
FM970390e			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				146	7528	71	23	215		74	125	37	29		
FM970390ee			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				232	9126	89	26	246	3	77	141	40	31		
FM970390f			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				176	7873	70	18	233	2	68	131	39	27		
FM970390ff			Angular debitage	debitage	Bruker Tracer 5i	not obsidian				79	1339	36		3	45		11				
FM970390g			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				205	7544	71	24	223	2	74	137	41	29		
FM970390gg			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				194	8518	84	20	238		79	140	42	27		

ID	Prov	Sub.prov	Type	Description	Instrument	Source	K	Ca	Ti	Mn	Fe	Zn	Ga	Rb	Sr	Y	Zr	Nb	Th	Ba	Pb
FM970390h			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				197	8848	80	22	246	2	86	147	52	30		
FM970390hh			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				227	8232	77	25	239	3	77	139	42	27		
FM970390i			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				184	8331	83	19	230		75	131	40	30		
FM970390ii			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				190	7653	72	17	224	2	70	137	40	27		
FM970390j			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				192	7826	88	26	227	3	73	129	42	27		
FM970390jj			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				199	8539	76	20	238		71	135	43	27		
FM970390k			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				230	8166	85	23	227		82	141	47	27		
FM970390l			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				187	8259	82	19	242	2	82	142	46	29		
FM970390ll			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				215	8233	80	21	229	2	82	141	46	28		
FM970390m			Point	biface point	Bruker Tracer 5i	Obsidian Cliff				262	8286	118	25	239	3	78	144	42	34		
FM970390mm			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				177	8556	75	16	237		79	141	44	24		
FM970390n			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				200	8186	130	26	231	2	76	146	44	26		
FM970390nn			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				176	9092	70	16	255		83	147	46	31		
FM970390o			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				317	10820	89	26	248	3	81	149	41	30		
FM970390oo			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				198	7391	72	20	212		69	125	37	25		
FM970390p			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				200	9636	80	14	249		84	154	45	26		
FM970390pp			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				225	8186	80	22	226	2	69	132	41	28		
FM970390q			Angular debitage	debitage	Bruker Tracer 5i	not obsidian				126	8681	643	106	12	13	23	10		45		
FM970390qq			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				188	8665	90	21	252	3	77	140	47	30		
FM970390r			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				273	8783	90	24	242	3	81	149	45	27		
FM970390rr			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				218	8418	74	20	251		78	149	42	28		
FM970390s			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				192	8664	78	21	236		75	138	40	29		
FM970390ss			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				181	7398	81	12	215	3	68	125	38	23		
FM970390t			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				218	8291	73	19	244	2	78	144	46	29		
FM970390tt			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				200	9306	83	16	251	2	79	136	43	25		
FM970390u			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				201	8234	76	22	231		79	142	46	26		
FM970390uu			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				203	8277	74	22	230		73	138	44	27		
FM970390v			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				204	8273	75	20	228	2	76	138	39	30		
FM970390vv			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				223	8905	80	24	246	3	83	147	49	31		
FM970390w			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				212	8554	74	20	250		81	162	44	31		
FM970390ww			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				213	9005	85	24	250	3	79	139	45	29		
FM970390x			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				201	8310	71	19	219		76	131	40	27		
FM970390xx			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				188	7805	72	22	221	2	71	150	43	25		
FM970390y			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				186	8038	89	17	222	6	75	132	41	26		
FM970390yy			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				220	8658	74	24	232	3	78	140	43	32		
FM970390z			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				201	8008	75	22	236	2	78	140	43	28		
FM970390zz			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				220	8862	75	17	246		78	147	47	32		
FM970391.01			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				193	8466	80	21	230	2	77	136	43	32		
FM970391.02			Point	biface tip fragment	Bruker Tracer 5i	Obsidian Cliff				212	7943	106	17	223	4	74	133	39	26		
FM970391.03			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				155	8981	79	20	250	2	78	142	43	28		
FM970391.04			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				138	8917	72	16	234		80	137	44	24		
FM970391.05			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				218	8662	81	19	246	3	83	144	44	33		

ID	Prov	Sub.prov	Type	Description	Instrument	Source	K	Ca	Ti	Mn	Fe	Zn	Ga	Rb	Sr	Y	Zr	Nb	Th	Ba	Pb
FM970391.06			Biface	biface fragment	Bruker Tracer 5i	Bear Gulch				223	10247	102	14	164	39	42	249	50	22		
FM970391.07			Biface	debitage	Bruker Tracer 5i	Obsidian Cliff				233	8572	84	22	248		82	143	47	30		
FM970391.08			Point	biface fragment	Bruker Tracer 5i	Obsidian Cliff				146	7821	85	13	217	3	66	125	37	28		
FM970391.09			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				207	8316	84	22	225		80	144	43	29		
FM970391.10			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				179	8442	80	19	220		75	128	39	28		
FM970391.11			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				157	7977	78	13	217	3	66	123	43	26		
FM970391.12			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				183	7862	76	17	215		74	133	41	26		
FM970391.13			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				243	8988	80	26	236	3	77	144	44	28		
FM970391.14			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				171	8167	87	19	231		77	132	42	23		
FM970391.15			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				180	8222	74	21	221	3	75	144	40	27		
FM970391.16			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				168	7678	63	17	212		70	138	40	31		
FM970391.17			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				150	8492	83	26	237	2	83	141	44	29		
FM970391.18			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				208	8536	74	18	242	3	74	140	43	30		
FM970391.19			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				189	8477	75	23	239		83	144	46	30		
FM970391.20			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				147	8415	82	18	228		80	138	43	30		
FM970391.21			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				169	7573	80	19	213		74	137	42	32		
FM970391.22			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				167	7912	77	18	225		74	132	43	27		
FM970391.23			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				112	7434	82	13	197		69	114	38	21		
FM970391.24			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				155	8180	67	11	225		71	133	36	23		
FM970391.25			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				204	7618	73	23	213		69	129	43	27		
FM970391.26			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				366	11200	82	16	229	6	76	153	44	27		
FM970391.27			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				161	8520	85	15	234		74	139	44	25		
FM970391.28			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				183	8382	80	25	248		81	143	48	31		
FM970391.29			Point	biface point fragment	Bruker Tracer 5i	Obsidian Cliff				181	8180	89	21	249	2	79	154	41	29		
FM970391.30			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				150	8529	91	16	224		73	135	42	25		
FM970391.31			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				263	10355	79	17	239	3	81	144	43	29		
FM970391.32			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				235	8369	78	24	234		81	145	43	27		
FM970391.33			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				294	9315	79	23	251		78	152	44	34		
FM970391.34			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				158	8148	78	18	226		72	135	43	25		
FM970391.35			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				173	9031	70	15	238	2	76	141	42	30		
FM970391.36			Ross Point	tanged point proximal fragment	Bruker Tracer 5i	Obsidian Cliff				143	8894	77	12	233		76	136	43	25		
FM970391.37			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				211	8113	86	22	232	3	82	147	43	28		
FM970391.38			Biface	isolated tang	Bruker Tracer 5i	Obsidian Cliff				168	8013	77	15	227	3	75	137	42	24		
FM970391.39			Biface	biface fragment	Bruker Tracer 5i	Obsidian Cliff				164	8193	70	21	214	2	72	130	39	27		
FM970391.40			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				148	8326	89	18	233		72	134	42	24		
FM970391.41			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				153	8941	137	15	243	3	79	136	44	33		
FM970391.42			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				198	8449	73	18	239		76	146	44	31		
FM970391.43			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				183	8591	78	16	233		78	133	43	31		
FM970391.44			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				162	8455	89	16	239		71	141	44	29		
FM970391.45			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				218	9334	74	18	250	2	80	141	45	30		
FM970391.46			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				190	8470	75	21	230		78	136	43	26		
FM970391.47			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				194	8124	76	18	226		77	135	39	28		
FM970391.48			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				227	8161	77	22	232		75	146	44	27		

ID	Prov	Sub.prov	Type	Description	Instrument	Source	K	Ca	Ti	Mn	Fe	Zn	Ga	Rb	Sr	Y	Zr	Nb	Th	Ba	Pb
FM970391.49			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				216	8265	76	16	225		75	135	42	24		
FM970391.50			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				198	8444	81	18	227	2	77	139	41	29		
FM970391.51			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				339	8974	177	24	218	10	78	147	42	29		
FM970391.52			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				193	8324	80	21	237		74	141	42	28		
FM970391.53			Angular debitage	debitage	Bruker Tracer 5i	Bear Gulch				319	9977	219	15	159	41	42	244	52	22		
FM970391.54			Angular debitage	debitage	Bruker Tracer 5i	Bear Gulch				304	10599	67	17	165	38	40	256	48	23		
FM970391.55			Angular debitage	debitage	Bruker Tracer 5i	Bear Gulch				361	10778	65	18	169	39	42	267	52	23		
FM970391.56			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				133	9536	82	12	246	4	70	134	40	33		
FM970391.57			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				189	8775	82	16	244	3	75	143	42	27		
FM970391.58			Biface	biface tip fragment	Bruker Tracer 5i	Obsidian Cliff				233	8676	80	20	242	3	87	152	46	32		
FM970391.59			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				221	8276	91	22	239	3	75	144	47	30		
FM970391.60			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				196	7655	70	22	228	2	73	134	41	30		
FM970391.61			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				203	8561	79	23	237		75	141	44	30		
FM970391.62			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				176	8446	75	21	232		81	149	44	30		
FM970391.63			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				272	8141	158	24	228	3	78	138	45	28		
FM970391.64			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				187	9769	84	17	257	3	84	143	41	30		
FM970391.65			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				199	7867	74	22	227	3	78	144	42	26		
FM970391.66			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				222	8457	117	24	243		79	142	44	27		
FM970391.67			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				248	8351	80	24	235	2	76	136	44	27		
FM970391.68			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				374	8040	92	29	222	4	76	134	43	30		
FM970391.69			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				207	8074	71	21	229	2	74	138	44	25		
FM970391.70			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				235	8437	72	19	240		77	144	41	28		
FM970391.71			Angular debitage	debitage	Bruker Tracer 5i	Bear Gulch				359	11607	68	16	178	40	46	267	54	23		
FM970391.72			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				148	8430	68	10	226	3	84	140	45	29		
FM970391.73			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				186	7823	85	17	221		73	134	42	28		
FM970391.74			Biface	biface fragment	Bruker Tracer 5i	Obsidian Cliff				272	8133	141	12	208	26	71	129	38	25		
FM970391.75			Biface	biface tip fragment	Bruker Tracer 5i	Bear Gulch				451	11289	276	18	168	43	40	254	54	22		
FM970391.76			Biface	biface tip fragment	Bruker Tracer 5i	Obsidian Cliff				162	8414	75	18	240	2	80	143	45	29		
FM970391.77			Point	biface proximal fragment	Bruker Tracer 5i	Bear Gulch				403	11442	116	17	179	41	40	261	50	21		
FM970391.78			Biface	biface fragment	Bruker Tracer 5i	Obsidian Cliff				160	6945	72	20	200		64	122	38	24		
FM970391.79			Biface	biface fragment	Bruker Tracer 5i	Obsidian Cliff				156	8415	219	15	245		77	142	46	28		
FM970391.80			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				189	8786	82	20	230	3	72	133	37	25		
FM970391.81			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				186	8178	77	19	227	2	77	140	39	28		
FM970391.82			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				172	7513	63	13	209		72	128	40	22		
FM970392.01			Flake core	core	Bruker Tracer 5i	Obsidian Cliff				199	8251	90	41	236	2	82	141	46	42		
FM970392.02			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				196	9838	94	21	268		91	158	49	27		
FM970392.03			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				156	8019	81	16	219		69	123	41	25		
FM970392.04			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				129	7459	75	16	208		68	126	42	28		
FM970392.05			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				133	7896	73	13	220		72	129	41	27		
FM970392.06			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				137	8061	69	14	208		74	128	38	24		
FM970392.07			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				171	8748	91	11	230		71	148	40	31		
FM970392.08			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				144	7694	75	18	216		68	122	36	27		
FM970392.09			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				124	7627	76	12	213	3	72	121	40	23		

ID	Prov	Sub.prov	Type	Description	Instrument	Source	K	Ca	Ti	Mn	Fe	Zn	Ga	Rb	Sr	Y	Zr	Nb	Th	Ba	Pb
FM970392.10			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				193	8290	75	24	232	2	74	133	40	28		
FM970392.11			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				202	8546	84	19	237	2	78	137	41	27		
FM970392.12			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				123	7782	78	8	203		67	118	34	24		
FM970392.13			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				212	8231	78	18	234		78	145	44	27		
FM970392.14			Flake core	core	Bruker Tracer 5i	Obsidian Cliff				202	8027	83	20	220	3	81	137	42	29		
FM970392.15			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				185	8758	92	25	240		75	142	46	26		
FM970392.16			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				193	7981	90	22	226	2	75	136	42	27		
FM970392.17			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				141	9150	78	13	231	3	82	137	38	26		
FM970393.01			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				130	8992	88	21	248	3	79	142	45	33		
FM970393.02			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				134	7649	74	12	212		68	123	41	22		
FM970393.03			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				229	8080	71	23	239	2	80	147	46	29		
FM970393.04			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				184	9358	92	16	251		79	146	45	31		
FM970393.05			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				141	10537	96	13	248	3	84	143	43	33		
FM970393.06			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				139	8683	81	11	240		79	134	41	28		
FM970393.07			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				130	7806	73	17	224	2	71	133	40	26		
FM970393.08			Biface	biface fragment	Bruker Tracer 5i	Obsidian Cliff				176	8027	65	18	232	2	74	137	44	26		
FM970393.09			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				221	8356	79	18	236	2	79	144	45	31		
FM970393.10			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				190	8027	67	17	223	2	77	140	39	28		
FM970393.11			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				198	8178	70	18	232	2	74	142	41	28		
FM970393.12			Point	biface fragment	Bruker Tracer 5i	Obsidian Cliff				236	8176	207	20	244	5	78	143	45	27		
FM970393.13			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				103	7436	79	7	207		73	122	42	25		
FM970393.14			Angular debitage	debitage with cortex	Bruker Tracer 5i	Obsidian Cliff				212	8395	75	24	226		75	135	39	26		
FM970393.15			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				153	7849	85	14	218		71	124	35	24		
FM970393.16			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				182	8277	80	18	233	2	78	133	41	28		
FM970393.17			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				176	7853	77	18	218	3	76	132	45	33		
FM970393.18			Angular debitage	debitage with cortex	Bruker Tracer 5i	Obsidian Cliff				136	7009	60	9	186	3	69	108	29	26		
FM970393.19			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				235	9074	90	24	257	2	82	147	43	31		
FM970393.20			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				187	8275	91	18	231		80	135	41	28		
FM970393.21			Point	biface proximal fragment	Bruker Tracer 5i	Obsidian Cliff				168	8409	87	20	249	2	80	147	43	28		
FM970393.22			Point	biface medial fragment	Bruker Tracer 5i	Obsidian Cliff				205	8573	117	19	255	3	85	148	45	29		
FM970393.23			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				155	7333	69	21	207	2	69	133	38	23		
FM970393.24			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				189	8376	81	22	238		78	146	42	29		
FM970393.25			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				194	8477	76	21	243		75	142	44	28		
FM970393.26			Point	biface point distal fragment	Bruker Tracer 5i	Bear Gulch				358	11335	71	16	168	41	43	274	55	23		
FM970393.27			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				188	7766	77	18	232	2	80	145	44	27		
FM970393.28			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				159	8115	87	17	228	2	78	132	41	30		
FM970393.29			Angular debitage	debitage with drilled hole	Bruker Tracer 5i	Obsidian Cliff				151	8530	79	12	223		77	130	47	29		
FM970393.30			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				241	8754	82	22	246	2	82	144	47	28		
FM970393.31			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				182	7556	82	18	210	3	70	124	44	25		
FM970393.32			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				169	8189	74	15	230	2	77	135	41	28		
FM970393.33			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				134	8247	75	14	222		78	133	42	26		

ID	Prov	Sub.prov	Type	Description	Instrument	Source	K	Ca	Ti	Mn	Fe	Zn	Ga	Rb	Sr	Y	Zr	Nb	Th	Ba	Pb
FM970393.34			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				133	8099	73	8	216		75	127	44	29		
FM970393.35			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				157	7564	72	14	210		74	124	41	26		
FM970393.36			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				156	7740	86	17	213	3	75	129	41	28		
FM970393.37			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				167	7824	68	14	220	3	74	129	44	26		
FM970393.38			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				159	7689	68	18	219	2	76	132	43	26		
FM970393.39			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				126	7810	74	12	215	3	69	122	39	29		
FM970393.40			Point	biface point distal fragment	Bruker Tracer 5i	Obsidian Cliff				244	8278	116	17	227	4	76	136	44	27		
FM970393.41			Point	biface point proximal fragment	Bruker Tracer 5i	Obsidian Cliff				164	8976	82	11	238		81	138	40	29		
FM970393.42			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				152	7900	77	21	219		68	132	42	28		
FM970393.43			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				201	9181	85	27	256	2	85	153	49	29		
FM970393.44			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				185	8202	69	17	233	2	81	136	46	30		
FM970393.45			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				197	8233	77	16	221	3	77	131	42	27		
FM970393.46			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				192	7433	75	18	214		68	128	40	26		
FM970393.47			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				180	7926	83	22	220		76	134	41	25		
FM970393.48			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				219	8078	79	22	231	2	74	133	46	26		
FM970393.49			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				122	8739	75	10	234		77	143	41	26		
FM970393.50			Flake	debitage	Bruker Tracer 5i	Obsidian Cliff				188	8854	79	20	232		72	143	46	28		
FM970393.51			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				310	8785	344	23	241	4	72	139	43	27		
FM970393.52			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				146	7832	63	15	215		73	131	42	25		
FM970393.53			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				225	8263	80	26	231	2	81	144	45	28		
FM970393.54			Ross Point	biface point medial fragment	Bruker Tracer 5i	Obsidian Cliff				186	8142	91	18	235	3	81	142	45	28		
FM970393.55			Point	biface point distal fragment	Bruker Tracer 5i	Obsidian Cliff				256	8006	110	26	226	3	76	133	42	29		
FM970393.56			Point	biface point distal fragment	Bruker Tracer 5i	Obsidian Cliff				242	9251	285	28	219	13	81	137	43	29		
FM970393.57			Point	biface point distal fragment	Bruker Tracer 5i	Obsidian Cliff				174	7997	84	19	234		82	143	45	26		
FM970393.58			Ross Point	biface point distal fragment	Bruker Tracer 5i	Obsidian Cliff				216	8582	140	16	237	6	77	142	47	29		
FM970394a			Triangular Bottom Ross Knife	biface knife proximal fragment	Bruker Tracer 5i	Obsidian Cliff				181	7287	76	19	202		71	122	35	27		
FM970394b			Triangular Bottom Ross Knife	biface knife	Bruker Tracer 5i	Obsidian Cliff				166	8748	86	14	239	3	79	142	42	29		
FM970394c			Ross Knife	biface knife	Bruker Tracer 5i	Bear Gulch				292	10993	191	11	168	38	40	248	51	21		
FM970394d			Ross Knife	biface knife proximal fragment	Bruker Tracer 5i	Obsidian Cliff				127	7433	84	11	210	2	69	122	41	26		
FM970394e			Ross Point	biface point	Bruker Tracer 5i	Bear Gulch				311	10434	119	15	165	38	39	250	47	21		
FM970394f			Biface	biface knife proximal fragment	Bruker Tracer 5i	Obsidian Cliff				191	9460	91	24	236		84	144	43	30		
FM970394g			Ross Knife	biface point proximal fragment	Bruker Tracer 5i	Bear Gulch				285	10716	93	11	166	38	37	243	48	25		
FM970394h			Ross Knife	biface knife proximal fragment	Bruker Tracer 5i	Obsidian Cliff				145	7793	98	19	201	5	70	122	41	26		
FM970394i			Ross Knife	biface knife proximal fragment	Bruker Tracer 5i	Bear Gulch				137	9948	41	7	147	36	38	232	47	22		
FM970395a			Ross Knife	biface knife proximal fragment	Bruker Tracer 5i	Bear Gulch				330	11655	188	25	174	42	43	267	55	25		
FM970395b			Ross Point	biface point proximal fragment	Bruker Tracer 5i	Obsidian Cliff				186	7640	96	18	224		77	133	41	28		
FM970395c			Ross Knife	biface knife proximal fragment	Bruker Tracer 5i	Obsidian Cliff				153	8554	85	20	234		74	137	41	29		
FM970395d			Triangular Bottom Ross Knife	biface knife proximal fragment	Bruker Tracer 5i	Obsidian Cliff				198	8762	74	19	244	2	79	143	48	31		
FM970395e			Ross Knife	biface knife proximal fragment	Bruker Tracer 5i	Obsidian Cliff				223	8349	198	11	190	15	66	120	36	23		
FM970396a			Biface	biface knife proximal fragment	Bruker Tracer 5i	Obsidian Cliff				120	9271	89	12	221	5	73	129	39	26		
FM970396b			Biface	biface knife proximal fragment	Bruker Tracer 5i	Bear Gulch				203	11261	112	11	163	38	40	250	47	21		

ID	Prov	Sub.prov	Type	Description	Instrument	Source	K	Ca	Ti	Mn	Fe	Zn	Ga	Rb	Sr	Y	Zr	Nb	Th	Ba	Pb
FM970396c			Biface	biface point proximal fragment	Bruker Tracer 5i	Obsidian Cliff				157	7710	92	15	216	2	71	128	41	24		
FM970396d			Ross Knife	biface knife distal fragment	Bruker Tracer 5i	Obsidian Cliff				171	8125	154	14	219	5	70	125	39	25		
FM970396e			Ross Knife	biface knife distal fragment	Bruker Tracer 5i	Obsidian Cliff				136	8046	79	13	219		73	130	40	27		
FM970396f			Ross Knife	biface knife distal fragment	Bruker Tracer 5i	Obsidian Cliff				153	8039	113	22	221		78	131	42	34		
FM970397a			Biface	biface knife medial fragment	Bruker Tracer 5i	Obsidian Cliff				146	8329	111	7	236		74	135	41	26		
FM970397b			Biface	biface knife proximal fragment	Bruker Tracer 5i	Obsidian Cliff				101	7821	80	6	198		79	120	34	28		
FM970397c			Point	biface point distal fragment	Bruker Tracer 5i	unassigned 1				297	10596	103	11	157	59	40	250	46	19		
FM970397d			Ross Knife	biface knife distal fragment	Bruker Tracer 5i	Obsidian Cliff				128	7400	135	12	203	3	66	129	36	29		
FM970397e			Biface	biface knife medial fragment	Bruker Tracer 5i	Obsidian Cliff				123	8516	219	18	234		77	142	44	29		
FM970397f			Ross Knife	biface knife proximal fragment	Bruker Tracer 5i	Obsidian Cliff				144	8056	134	8	202	6	71	131	40	30		
FM970397g			Ross Knife	biface knife distal fragment	Bruker Tracer 5i	Bear Gulch				163	12564	92	11	176	37	44	257	48	23		
FM970398a			Biface	biface knife medial fragment	Bruker Tracer 5i	Obsidian Cliff				202	8525	146	17	239		78	134	40	27		
FM970398b			Biface	biface knife medial fragment	Bruker Tracer 5i	Obsidian Cliff				185	9062	91	16	255	3	85	154	44	33		
FM970398c			Biface	biface knife distal fragment	Bruker Tracer 5i	Obsidian Cliff				133	8048	118	16	219		70	126	43	25		
FM970398d			Biface	biface knife medial fragment	Bruker Tracer 5i	Obsidian Cliff				175	8242	107	15	227		79	134	45	29		
FM970398e			Biface	biface knife proximal fragment	Bruker Tracer 5i	Obsidian Cliff				116	7797	85	50	221		78	125	39	49		
FM970398f			Biface	biface knife distal fragment	Bruker Tracer 5i	Obsidian Cliff				284	9117	106	23	255	3	83	144	39	36		
FM970398g			Biface	biface knife medial fragment	Bruker Tracer 5i	Obsidian Cliff				130	9388	94	10	243		84	137	38	32		
FM970398h			Biface	biface knife medial fragment	Bruker Tracer 5i	Obsidian Cliff				168	7570	118	12	197	5	68	120	35	21		
FM970398i			Flat-based Point	biface point proximal fragment	Bruker Tracer 5i	Obsidian Cliff				212	8401	96	20	228	2	71	140	41	28		
FM970398j			Biface	biface medial fragment	Bruker Tracer 5i	Bear Gulch				231	11233	62	8	166	37	39	251	52	24		
FM970399a			Biface	biface medial fragment	Bruker Tracer 5i	Bear Gulch				254	11261	186	14	172	41	43	263	55	22		
FM970399b			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				162	7768	101	22	218		70	130	37	26		
FM970399c			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				138	9119	101	10	243		70	145	42	31		
FM970399d			Ross Point	biface point proximal fragment	Bruker Tracer 5i	Obsidian Cliff				214	8058	121	22	232		74	144	45	29		
FM970399e			Biface	biface proximal fragment	Bruker Tracer 5i	Bear Gulch				234	10091	135	10	152	36	40	232	51	19		
FM970399f			Point	biface knife distal fragment	Bruker Tracer 5i	Obsidian Cliff				199	8552	133	15	223	4	74	124	39	29		
FM970399g			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				196	7916	449	22	227	6	75	128	39	32		
FM970399h			Angular debitage	debitage	Bruker Tracer 5i	Bear Gulch				255	11073	67	16	172	37	42	252	51	21		
FM970399i			Biface	biface medial fragment	Bruker Tracer 5i	unassigned 2				107	8504	104	128	238	6	129	136	38	176		
FM970399j			Biface	biface medial fragment	Bruker Tracer 5i	Obsidian Cliff				146	8013	75	14	227		69	129	39	21		
FM970399k			Biface	biface proximal fragment	Bruker Tracer 5i	Obsidian Cliff				128	8190	87	20	235		71	134	39	27		
FM970399l			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				124	8217	96	12	225		71	127	41	27		
FM970399m			Angular debitage	debitage	Bruker Tracer 5i	Obsidian Cliff				217	8115	92	25	233		77	133	46	30		
FM970399n			Angular debitage	debitage	Bruker Tracer 5i	Bear Gulch				271	11102	219	10	168	39	48	243	50	24		

Chapter 4

Emergent Economic Networks in the American Southwest

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Abstract

The American Southwest has been the focus of major multidisciplinary anthropological research programs since the late 1800s. However, no longer as constrained by artificial culture historical categories, the applications of new technologies have made it possible to reconstruct and reinterpret early interactions and social relations in the Southwest. This paper synthesizes previously published sourced obsidian data (n=478) from 30 sites situated in New Mexico and Arizona dating between the Paleoindian and Late Archaic phases (10,500 BCE – ~250 CE) to define shifting networks of economic transfer and interaction over time.

Introduction

As archaeological fieldwork increases throughout North America, more materials are accumulating in CRM storage facilities, museum collections, and university laboratory repositories. Although some preliminary analyses may be conducted on these materials, a vast majority of all finds are catalogued, tagged, boxed, and stored in perpetuity with little to no subsequent analyses conducted. Reports that are generated typically are site-based and often lack contextualization in broader regional contexts. In turn, such investigatory practices also have resulted in the consignment of a plethora of data to marginalized site reports and/or descriptive publications.

The accumulation of stored materials and data is not a new occurrence and has, in fact, been a customary approach in the United States for managing archaeological materials since the early 1900s. The result of this managerial tradition is the creation of untapped data troves. To the right researcher willing to carefully mine the data for the information that they can yield, these various datasets can be synthesized and used to develop new questions and interpretations regarding the past.

Beyond utilizing the data for synchronic descriptions, the synthesis of larger suites of data can be employed to understand diachronic changes. This is not a novel approach, and it should be stressed that other intrepid researchers have already initiated data synthesis projects with great success. Since the 1980's, M. Steven Shackley has been identifying and compositionally characterizing the various obsidian geological sources in the Southwest (Shackley 2005). Incorporating this research, Barbara Mills and her colleagues (Mills *et al.* 2013, 2015, 2019) have been working for many years on the CyberSW archive. Their research has expanded on Shackley's original research to illustrate the complex networks of exchange and mobility in the later pre-contact Southwest, through the study of obsidian exploitation and exchange in conjunction with other suites of archaeological data.

Although the investigations by Mills and colleagues have opened important new lines of synthetic analysis, their research has focused on the later Prehispanic period, from 1200–1450 CE, with some of their data going back as early as 800 CE. To date, earlier periods have not received such attention. Is it possible to begin to synthesize data for earlier times? And if so, what could be learned by documenting patterns of exchange and interaction during earlier times in the Southwest? We start to address these questions using preliminary results from a synthesis project that focuses on obsidian materials (n=478) from 30 sites in New Mexico and Arizona dating to the Paleoindian (before 6,500 BCE), Archaic (6,500 – 1,200 BCE), and Pre-Pottery/Late Archaic phases (1,200

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BCE – ~250 CE; moving forward, referred to as just Late Archaic).

Background

The Field Museum of Natural History has a long history of collecting, curating, and preserving the archaeological past. Inadvertently, the institution also has become one of the aforementioned curation centers that houses an array of materials awaiting further study. To address this issue, the Field Museum encourages researchers from all around the world to submit proposals to work with materials in its collections. The institution also has invested in various instrumentation technologies to facilitate the investigation of collections in innovative ways (see Dussubieux *et al.* 2007; Dussubieux and Walder 2022).

At the Field Museum, the largest collection of archaeological materials from the Southwest is the Paul S. Martin Collection, which includes materials recovered during a career of fieldwork conducted during the mid-20th century. A rehousing project for these materials in this collection was completed with funding from the National Science Foundation (SBR-9710181) in the late 1990's, and it brought to light how extensive the collection was in terms of organic materials (Koons and Nash 2015; McBrinn 2005) and chipped stone artifacts (Nash and Koons 2015; Riebe *et al.*, *in press*). Specifically, the obsidian materials from this collection totaled over 550 artifacts from 29 different sites that Martin investigated while curator at the Field Museum. The obsidian artifacts from one site, Tularosa Cave (n=17) were compositionally analyzed in the early 2000's (see Nash and Koons 2015), but the remainder were left unstudied until the implementation of the current investigation.

Reserve Region

The initial focus of this study centered on the Reserve area as several of the Martin sites are situated in this region. The largest obsidian assemblage (n=180) from a single site in the Martin Collection was recovered from the site of O Block Cave. Materials from this site were employed as a case study to see if diachronic sourcing patterns could be identified. Compositional analysis of the obsidian artifacts was conducted using a Thermo Scientific Niton XL3t Goldd + portable X-ray fluorescence (pXRF) instrument housed in the Elemental Analysis Facility (EAF) at the Field Museum (for instrument setting information see Riebe *et al.* 2018). The results illustrated that obsidian consumption changed over time, with a decrease in overall consumption occurring after the introduction of farming in the region. However, coincident with this shift in subsistence production, there was also an increase in non-local materials, which was interpreted to reflect a broader exchange network (Riebe *et al.* 2018; see Riebe *et al.* in this volume to learn more about the issues encountered with this study).

Based on these preliminary findings from O Block Cave, an expansion of the compositional analysis to the other obsidian artifacts in the Martin Collection was undertaken. Eleven additional Martin sites and their obsidian assemblages (n=504) primarily from the Reserve region were included to examine changing patterns in obsidian procurement. Local sources dominated each obsidian assemblage for all sites in each period. But at Pueblo sites in this sample, non-local sources were associated only with kiva contexts, which would seem to indicate that shifts in obsidian exchange were associated with changing socio-cultural practices (Riebe *et al.*, *in press*).

Study – Regional Synthesis

Both of these initial studies, which drew on the Martin Collection, have laid a foundation for further broadening the scope of our investigations in the Southwest. With the Reserve region at the heart of these studies, the question remained: Are the procurement patterns identified in the obsidian assemblages from the sites associated with Martin's fieldwork representative of broader macroregional patterns in the Southwest or are they merely a local phenomenon for the Reserve region? Moreover, how do these identified patterns of exploitation relate to even earlier periods of human occupation in the region?

To address these questions, the authors aggregated an archive of published Southwestern obsidian data that supplements the compositional studies of the Martin Collection. Various sources, including academic publications, lab publications, and various masters and doctoral theses, were reviewed to acquire previously disseminated obsidian compositional data. The archive, known as the SW Obsidian Sites and Sources Database, remains a work in progress, but it currently includes 415 sites and approximately 12,768 sourced obsidian artifacts, which date from the Paleoindian (before 6500 BCE) to Late Pueblo (up to 1650 CE) phases of occupation.

Compounding Issues

However, as work continued on the SW Obsidian Sites and Sources Database, numerous issues emerged in regard to how, where, when, why, and what data are recorded and published. Bearing in mind the long history of archaeological research in the American Southwest, it is not surprising that there are inconsistencies in the records, but these inconsistences have resulted in compounding issues that have made it exceedingly difficult to synthesize data. For instance, when it came

Table 4.1. Summary of the periods included in this study with the total number of sites and obsidian artifacts associated with each period.

Period	Phase	Dates	Number of Sites	Number of Obsidian
Period 3	Pre-Pottery	1200 BCE - AD 250	9	158
Period 2	Archaic	6500 BCE - 1200 BCE	19	318
Period 1	Paleoindian	Before 6500 BCE	2	2
		TOTAL	30	478

to identifying the coordinates for all of the sites in our regional obsidian database, it was determined that issues existed with site naming conventions and site recording methods, which could vary depending on the local, regional, and state levels. A unified archaeological site database for the entirety of the Southwest (or the U.S. for that matter) does not exist, however, state-level archaeological site databases are maintained. Access to those databases tends to be restricted to only verified (and sometimes paying) users, which results in another limiting factor to contend with. However, even with access to the state-level databases, site identification is still difficult if not impossible when only colloquially used site names are referenced in publications. The New Mexico and Arizona state site databases record archaeological sites with specific naming conventions, recorded as Arizona State Museum (ASM) site number for Arizona and Laboratory of Anthropology (LA) site number for New Mexico. Neither Arizona nor New Mexico uses the standard Smithsonian Site ID system common throughout most of the US, and this is further complicated by certain land agencies and other institutions that use independent IDs and databases. These include some tribal lands (such as the Navajo Nation) and military facilities (such as the Barry Goldwater Military Range).

Southwest Regional Synthesis Focus

In order to reconstruct patterns of obsidian exploitation, it was necessary to obtain the coordinate information for the sites in the SW Obsidian Sites and Sources Database. As this information was not always readily accessible, it became a limiting factor. Ultimately, we made the decision to narrow our focus to only those sites with definitively identified coordinates. Additionally, as our focus in the Martin studies concentrated on earlier temporal phases, we retain that chronological focus here. We therefore report on the earlier periods of occupation in the Southwest, including the Paleoindian, Archaic, and Late Archaic phases, which narrowed the scope of this preliminary synthesis to 30 sites and 478 sourced obsidian artifacts (Table 4.1; Appendix 4.1). Of these sites, Tularosa Cave, Cordova Cave, and O Block Cave are part of the Martin Collection previously studied by the authors (Riebe *et al.* 2018; Riebe *et al. in press*).

It should be noted that there are far more sites with sourced obsidian artifacts from the Archaic (n=318) and Late Archaic (n=158) periods than from the Paleoindian period (n=2), however, it is important to stress that this is a starting point for future research, and hopefully over time, additional sites will be included. The obsidian artifacts can be sourced to a total of 14 different geological sources located throughout the Southwest, and the number of sources identified at each site ranges

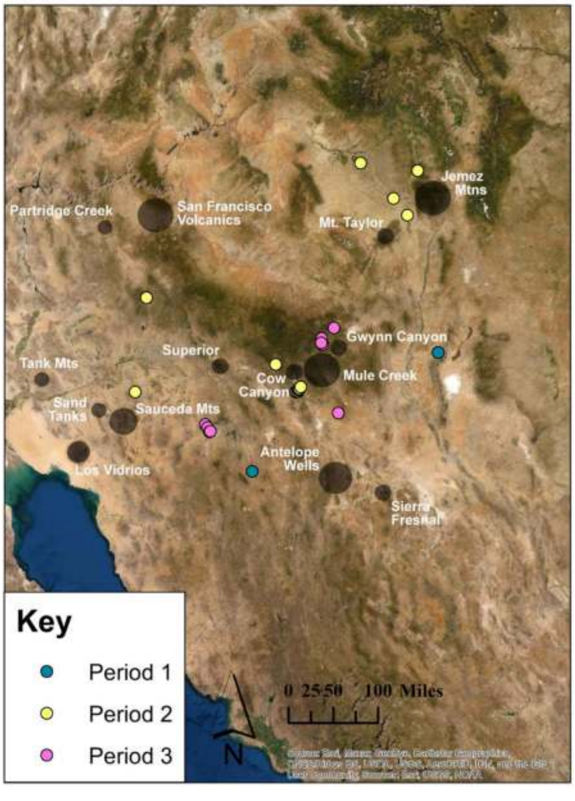

Figure 4.1. Sites included in the study with the relative location for each of the obsidian geological sources identified in the study (map adapted from geological source map in Shackley 2005).

Table 4.2. Sites included in the study arranged by subregion and period with the total number of obsidian artifacts for each site and their classification of local, non-local, or unsourced.

Period	Location	Site	# Obsidian	Local	Non-Local	Unsourced	Local%	Non-Local%	Unsourced%
1	South-Central New Mexico	LA 175204	1	0	1	0	0%	100%	0%
	Southeast Arizona	Murray Springs (NRHP reference No. 12001019)	1	0	1	0	0%	100%	0%
2	Southeast-Central Arizona	Cienega Creek (AZ W:10:112)	28	22	6	0	79%	21%	0%
		AZ CC:3:70	4	4	0	0	100%	0%	0%
		AZ CC:3:72	5	5	0	0	100%	0%	0%
		AZ CC:3:73	1	1	0	0	100%	0%	0%
		AZ CC:3:76	57	54	0	3	95%	0%	5%
		AZ CC:3:77	4	4	0	0	100%	0%	0%
		AZ CC:3:79	2	2	0	0	100%	0%	0%
		AZ CC:3:81	1	1	0	0	100%	0%	0%
		AZ CC:3:82	1	1	0	0	100%	0%	0%
		AZ CC:3:84	2	2	0	0	100%	0%	0%
		AZ CC:3:85	1	1	0	0	100%	0%	0%
		AZ CC:4:24	2	2	0	0	100%	0%	0%
	Central Arizona	AZ N:12:22	1	0	1	0	0%	100%	0%
		AZ N:12:25	9	0	8	1	0%	89%	11%
	South-Central Arizona	AZ CC:3:74	2	0	2	0	0%	100%	0%
	Northwest New Mexico	San Luis de Cabezon (LA 110946)	104	104	0	0	100%	0%	0%
		Encino Wash/MAPCO Project (LA 25673)	49	49	0	0	100%	0%	0%
		Mescalero Cave (LA 11033)	5	5	0	0	100%	0%	0%
		The Hilltop Bison Site (LA 172328)	40	0	40	0	0%	100%	0%
3	Southwest New Mexico	LA 99631	25	21	4	0	84%	16%	0%
	West-Central New Mexico	LA 43766	4	4	0	0	100%	0%	0%
		Tularosa Cave (LA 4427)	1	0	1	0	0%	100%	0%
		Cordova Cave (LA 174990)	50	50	0	0	100%	0%	0%
		O Block Cave (LA 29869)	60	60	0	0	100%	0%	0%
	South-Central Arizona	Las Capas (AZ AA:12:111)	9	2	7	0	22%	78%	0%
		Los Pozos (AZ AA:12:91)	1	0	1	0	0%	100%	0%
		Clearwater Site (AZ BB:13:6)	7	0	6	1	0%	86%	14%
		Tucson Presidio (AZ BB:13:13)	1	0	1	0	0%	100%	0%

Table 4.3. Sites included in the study arranged by subregion and period with the obsidian artifacts classified by source (TMC = all Mule Creek subsources; AW = Antelope Wells; TJEM = all Jemez Mountain subsources; CC = Cow Canyon; GC = Gwynn Canyon; LV = Los Vidrios; TMT = all Mount Taylor subsources; TMFVF = all Mount Floyd Volcanic Field subsources (including Partridge Creek); TSF = all San Francisco Volcanic Field subsources; SSM = Saucedo Mountains; ST = Sand Tanks; SUP = Superior; TANK = Tank Mountains)

Period	Site	TMC	AW	TJEM	CC	GC	LV	TMT	TMFVF	TSF	SF	SSM	ST	SUP	TANK	Unknown	Total
1	LA175204			1													1
	Murray Springs (NRHP reference No. 12001019)				1												1
2	Cienega Creek (AZ W:10:112)				22	6											28
	AZ CC:3:70	4															4
	AZ CC:3:72	5															5
	AZ CC:3:73	1															1
	AZ CC:3:76	41			13											3	57
	AZ CC:3:77	2			2												4
	AZ CC:3:79	2															2
	AZ CC:3:81	1															1
	AZ CC:3:82	1															1
	AZ CC:3:84	2															2
	AZ CC:3:85	1															1
	AZ CC:4:24	1			1												2
	AZ N:12:22									1							1
	AZ N:12:25								2	6						1	9
	AZ CC:3:74	1			1												2
	San Luis de Cabezon (LA 110946)			103				1									104
	Encino Wash/ MAPCO Project (LA 25673)			49													49
	Mescalero Cave (LA 11033)			5													5
	The Hilltop Bison Site (LA 172328)			40													40
3	LA 99631	19	1	3	1						1						25
	LA 43766	2				2											4
	Tularosa Cave (LA 4427)							1									1
	Cordova Cave (LA 174990)	30			5	15											50
	O Block Cave (LA 29869)	33			2	25											60
	Las Capas (AZ AA:12:111)	3										1	2	2	1		9
	Los Pozos (AZ AA:12:91)						1										1
	Clearwater Site (AZ BB:13:6)	1					1			2					2	1	7
	Tucson Presidio (AZ BB:13:13)														1		1

Table 4.4. Sites included in the study arranged by subregion and period with distance to obsidian geological sources identified at each site.

Period	Site	D. to TMC	D. to AW	D. to TJEM	D. to CC	D. to GC	D. to LV	D. to TMT	D. to TMFVF	D. to TSF	D. to SF	D. to SSM	D. to ST	D. to SUP	D. to TANK
1	LA 175204			160 mi											
	Murray Springs (NRHP reference No. 12001019)				110 mi										
2	Cienega Creek (AZ W:10:112)				25 mi	70 mi									
	AZ CC:3:70	25 mi													
	AZ CC:3:72	25 mi													
	AZ CC:3:73	25 mi													
	AZ CC:3:76	25 mi			20 mi										
	AZ CC:3:77	25 mi			20 mi										
	AZ CC:3:79	25 mi													
	AZ CC:3:81	25 mi													
	AZ CC:3:82	25 mi													
	AZ CC:3:84	25 mi													
	AZ CC:3:85	25 mi													
	AZ CC:4:24	25 mi			10 mi										
	AZ N:12:22									75 mi					
	AZ N:12:25								90 mi	75 mi					
	AZ CC:3:74	200 mi			170 mi										
	San Luis de Cabezon (LA 110946)			20 mi				30 mi							
	Encino Wash/MAPCO Project (LA 25673)			30 mi											
	Mescalero Cave (LA 11033)			20 mi											
	The Hilltop Bison Site (LA 172328)			75 mi											
3	LA 99631	40 mi	60 mi	260 mi	60 mi						100 mi				
	LA 43766	20 mi				10 mi									
	Tularosa Cave (LA 4427)							110 mi							
	Cordova Cave (LA 174990)	10 mi			40 mi	10 mi									
	O Block Cave (LA 29869)	10 mi			40 mi	10 mi									
	Las Capas (AZ AA:12:111)	130 mi										80 mi	110 mi	55 mi	170 mi
	Los Pozos (AZ AA:12:91)						130 mi								
	Clearwater Site (AZ BB:13:6)	120 mi					130 mi			210 mi					190 mi
	Tucson Presidio (AZ BB:13:13)														180 mi

from 1–3 source areas, including sub-source variants (Figure 4.1).

Previous research by the authors have assessed obsidian exploitation in the American Southwest based on local versus non-local materials, with local obsidian geological sources located 100km (approximately 62 miles) or less from the site of recovery and non-local defined as those sources situated more than 100km from the site of recovery (Riebe *et al. in press*). The same measures for obsidian classification as local and non-local are utilized in this study (Tables 4.2, 4.3 and 4.4). We realize this can be a seemingly arbitrary designation and complicating factors such as secondary deposits also come into play, but this study is looking at large-scale patterns that require some compromise. Based on the results obtained, it is possible to begin identifying how early interactions, as modeled by obsidian exploitation, reflect possible changing socioeconomic practices in the Southwest.

SW Obsidian Sites and Sources Results

Paleoindian (Period 1: Before 6,500 BCE)

Two sites date to the Paleoindian period (Table 4.2). The sites are located in Southeast Arizona (Murray Springs) and South-Central New Mexico (LA 175204), and neither site is located near any geological sources of obsidian (Figure 4.2). Each site had only one obsidian artifact and both were of non-local origin. The artifact from Murray Springs originated from Cow Canyon, whereas the obsidian specimen from LA 175204 was sourced to the Jemez Mountains (Tables 4.3, 4.4). In both instances, other obsidian sources are closer to the sites, and yet exploitation patterns indicate a possible north to south procurement pattern.

Archaic (Period 2: 6,500 – 1,200 BCE)

The largest sample in the study is for the Archaic period with 19 sites located in Southeast-Central Arizona, Central Arizona, South-Central Arizona, and Northwest New Mexico (Figure 4.2). Local materials make up a majority of the assemblages for the various sites, however, some sites only have non-local materials present (Table 4.2). For example, sites in Central Arizona and South-Central Arizona are dominated by non-local materials. As found for the Paleoindian period, the sites in Central Arizona obtained obsidian from sources located to the north, such as the San Francisco Volcanics and Partridge Creek (Table 4.3). The one site in South-Central Arizona procured obsidian from distant sources in the east, such as Cow Canyon and Mule Creek. This site is situated near several sources located to the south (Sauceda Mountains) and south-west (Sand Tanks), yet the obsidian artifacts from the site are from extremely long-distance sources to the east (Table 4.3). According to the definition of local and non-local that we employ, technically, the obsidians recovered and sourced from the Hilltop Bison Site (LA 172328) are all non-local as they come from the Jemez Mountains located approximately 120 km away (Table 4.4).

Late Archaic (Period 3: 1,200 BCE – 250 CE)

For the Late Archaic period, nine sites were included from three different subregions including Southwest New Mexico, West-Central New Mexico, and South-Central Arizona (Figure 4.2; Table 4.2). Again, site location seems to influence presence and frequency of non-local obsidians in the assemblages. Most of the obsidians from West-Central New Mexico are local and can be sourced to the Mule Creek, Cow Canyon, and Gwynn Canyon sources. Though one site, Tularosa

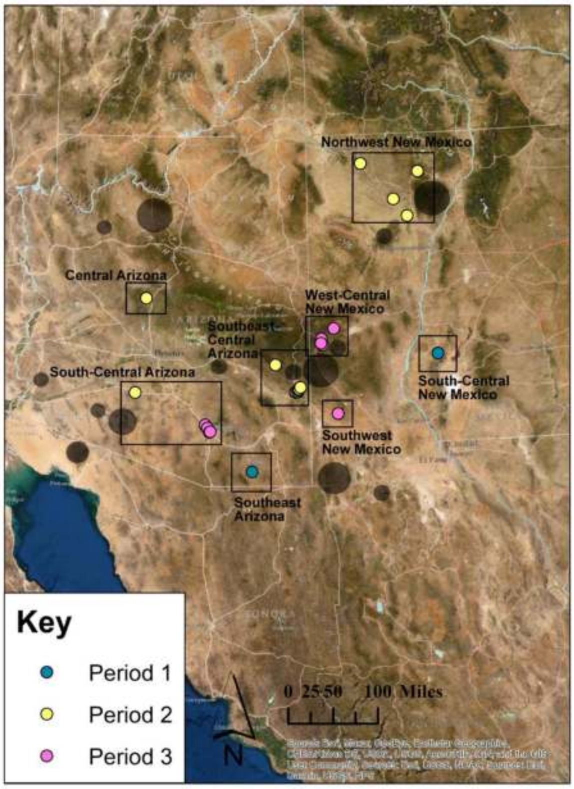

Figure 4.2. Sites included in the study with subregions identified and the relative location for each of the obsidian geological sources identified in the study (map adapted from geological source map in Shackley 2005).

Cave, has one obsidian artifact from the Mt. Taylor source located to the north (Table 4.3, 4.4). The site from the Southwest New Mexico subregion, LA 99631, primarily has local obsidian artifacts from the Mule Creek, Antelope Wells, and Cow Canyon sources, but it also has materials from the Jemez Mountains source in the north and the Sierra Fresnal source in the south (Table 4.3, 4.4). The South-Central Arizona sites are in a section of the Southwest that only has one local source, Superior. While Superior obsidian is present at one site (Las Capas, AZ AA:12:111), the remainder of assemblages for all other sites consist of obsidians from non-local sources to the east (Mule Creek), west (Los Vidrios, Sauceda Mountains, Sand Tanks, and Tank Mountains), and north (San Francisco Volcanics; see Table 4.3). Based on these data, the number of different sources utilized and networks of transfer seemingly increased during the Late Archaic period (Table 4.4).

Discussion and Synthesis

Overall, these data from the SW Obsidian Sites and Sources present an outline of shifting networks of exchange during the earliest periods of habitation in the American Southwest. The focus on networks as opposed to the mode of procurement is intentional as the obsidian data provide two clear lines of evidence: 1) point of geological origination based on compositional data and 2) point of deposition based on archaeological recovery. Focus on these aspects alone provide an opportunity to identify possible patterns in geological exploitation and to note if those patterns change over time.

From the Paleoindian to the Late Archaic periods (before 6,500 BCE – 250 CE), the archaeological data are sparser in the Southwest compared to later periods of occupation. Namely, it appears that a number of early Paleoindian sites in the Southwest are located near paleolakes in the region (Holliday *et al.* 2019: 93), and these sites were likely inhabited for shorter periods of time as people moved to follow the buffalo herds and to exploit other natural resources (Holliday *et al.* 2019: 137; Rivals and Semperbon 2012). As evidenced by the obsidian from the two Paleoindian sites in this study, obsidian geological sources were exploited early on, yet not intensively utilized. At both Paleoindian sites in the sample, the obsidian was procured from geological sources located to the north, illustrating that north to south networks were in place. However, the Paleoindian sample is extremely small (n=2), and thus any interpretations are highly speculative at this time.

During the Archaic period in the American Southwest, the movement of indigenous peoples became more tethered to specific regions. These places were generally rich in natural resources with reliable water sources, but varied in terms of access to specific environmental zones. As mobile foragers, Archaic peoples moved within these specific territories, setting up temporary campsites, and likely reoccupying a number of these locales over time (Roth 2013: 98). This developing sense of place may be tied to transforming networks of interaction across the broader region. The increased number of obsidian artifacts at sites dating to this time, along with multiple geological sources present at most Archaic sites, indicates that obsidian was more heavily exploited at this time. For sites in this sample, non-local obsidians are present in larger numbers at sites farther from geological sources, such as those located in Central and South-Central Arizona. While the site AZ CC:3:74 in the latter subregion is situated near the Sand Tanks and Sauceda Mountains sources, the obsidian recovered from this site only comes from long-distance geological sources to the north, again illustrating the developing complexity in exchange networks at this time.

In the latter half of the Archaic and into the Late Archaic period new subsistence strategies impacted peoples in the region. Although some sites have maize as early as 2,000 BCE, by 1,200 – 800 BCE maize becomes widely and increasingly incorporated into indigenous life (Roth 2013). However, maize does not completely replace earlier foraging subsistence strategies throughout the broader region, thus resulting in the emergence of the "farmager" in some places (Diehl 2005). Changes in subsistence strategies impacted settlement patterns as well. Sedentism appeared in some regions, with pit structures being the earliest form of built domestic structures in the Southwest (Love 2021; Roth 2013; Whalen 1994). The increasing commitment to place exhibited in the earlier half of the Archaic was strongly reinforced through the construction of these permanent dwellings. In turn, the exchange networks expanded spatially. Site location dramatically impacted patterns of exploitation. For instance, for those sites close to geological obsidian sources, including sites in West-Central New Mexico, local materials dominate the assemblages. Not surprisingly, sites farther from geological sources, such as those in the South-Central Arizona and Southwest New Mexico subregions, have more non-local obsidians present in their assemblages. When compared to earlier periods, more geological sources are exploited in the Archaic period likely reflecting increased interconnectivity between people across regions as settlements became more permanent in specific regions.

Conclusion

Although this study serves to expand on the analyses of materials housed at the Field Museum, more significantly it showcases the first synthesis of data from the SW Obsidian Sites and Sources Database. Numerous issues were encountered in the publication compilation process, specifically in terms of site naming conventions and site coordinates, which speak to larger concerns about how data in the Southwest are curated, shared, and accessed. Inter-state continuity regarding site data management would be ideal, but it would not magically fix the 100+ years of accumulated archaeological data from the region. Projects such as the SW Obsidian Sites and Sources Database present a way to synthesize previous research and obtain useful results. As work on the database continues, we will endeavor to fill in the gaps. To date, large syntheses of archaeological data in the American Southwest have primarily been restricted to later periods of occupation (see Mills *et al.* 2013, 2015, 2019), or have focused on specific subregions (see Taliaferro *et al.* 2010), but less attention has been given to reconstructing early indigenous interactions at the macro-regional scale. This preliminary effort illustrates how the archiving of archaeological samples from various site-based projects in conjunction with the spatial widening of the analytical lens can offer new macro-scale perspectives on long-term change, establishing a context for regional and macroregional histories.

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Appendix 4.1

Breakdown of the geological obsidian sources, sites, sourced materials, and previous publications from which data was mined.

Time Period	ID	Site	Modern State	N	# sources (all subsources)	TMC	AW	TJEM	CC	GC	LV	MDT	TMT	TMFVF	TSF	SF	SSM	ST	SUP	TANK	Unknown	Bib Source
1	105	LA175204	New Mexico	1	1			1														Dolan, S.G., Berryman, J., and Shackley, M.S. 2016. The Source Provenance of an Obsidian Eden Point from Sierra County, New Mexico. PaleoAmerica 2(1): 48–51.
1	163	Murray Springs (NRHP reference No. 12001019)	Arizona	1	1				1													Haynes, Jr., C.V. & Huckell, B.B. eds. 2007. Murray Springs, A Clovis Site with Multiple Activity Areas in the San Pedro Valley, Arizona. Tucson: University of Arizona Press. Print.
2	172	Cienega Creek (AZ W:10:112)	Arizona	28	2				22	6												Shackley, M.S. 2005. Obsidian: Geology and Archaeology in the North American Southwest. Tucson: Univeristy of Arizona Press. Print.
2	339	Site AZ CC:3:70	Arizona	4	1	4																Shackley, M.S. 2002. Source Provenance of Obsidian Artifacts from Mainly Archaic Contexts in the Tollgate and Tollhouse Canyon Region, Southeastern Arizona. UC Berkeley: Archaeological Research Facility. Report prepared for SWCA, Inc., Tucson, Arizona.
2	340	Site AZ CC:3:72	Arizona	5	2	5																Shackley, M.S. 2002. Source Provenance of Obsidian Artifacts from Mainly Archaic Contexts in the Tollgate and Tollhouse Canyon Region, Southeastern Arizona. UC Berkeley: Archaeological Research Facility. Report prepared for SWCA, Inc., Tucson, Arizona.
2	341	Site AZ CC:3:73	Arizona	1	1	1																Shackley, M.S. 2002. Source Provenance of Obsidian Artifacts from Mainly Archaic Contexts in the Tollgate and Tollhouse Canyon Region, Southeastern Arizona. UC Berkeley: Archaeological Research Facility. Report prepared for SWCA, Inc., Tucson, Arizona.
2	342	Site AZ CC:3:74	Arizona	2	2	1			1													Shackley, M.S. 2002. Source Provenance of Obsidian Artifacts from Mainly Archaic Contexts in the Tollgate and Tollhouse Canyon Region, Southeastern Arizona. UC Berkeley: Archaeological Research Facility. Report prepared for SWCA, Inc., Tucson, Arizona.
2	343	Site AZ CC:3:76	Arizona	57	4	41			13												3	Shackley, M.S. 2002. Source Provenance of Obsidian Artifacts from Mainly Archaic Contexts in the Tollgate and Tollhouse Canyon Region, Southeastern Arizona. UC Berkeley: Archaeological Research Facility. Report prepared for SWCA, Inc., Tucson, Arizona.

Time Period	ID	Site	Modern State	N	# sources (all subsources)	TMC	AW	TJEM	CC	GC	LV	MDT	TMT	TMFVF	TSF	SF	SSM	ST	SUP	TANK	Unknown	Bib Source
2	344	Site AZ CC:3:77	Arizona	4	2	2			2													Shackley, M.S. 2002. Source Provenance of Obsidian Artifacts from Mainly Archaic Contexts in the Tollgate and Tollhouse Canyon Region, Southeastern Arizona. UC Berkeley: Archaeological Research Facility. Report prepared for SWCA, Inc., Tucson, Arizona.
2	345	Site AZ CC:3:79	Arizona	2	1	2																Shackley, M.S. 2002. Source Provenance of Obsidian Artifacts from Mainly Archaic Contexts in the Tollgate and Tollhouse Canyon Region, Southeastern Arizona. UC Berkeley: Archaeological Research Facility. Report prepared for SWCA, Inc., Tucson, Arizona.
2	346	Site AZ CC:3:81	Arizona	1	1	1																Shackley, M.S. 2002. Source Provenance of Obsidian Artifacts from Mainly Archaic Contexts in the Tollgate and Tollhouse Canyon Region, Southeastern Arizona. UC Berkeley: Archaeological Research Facility. Report prepared for SWCA, Inc., Tucson, Arizona.
2	347	Site AZ CC:3:82	Arizona	1	1	1																Shackley, M.S. 2002. Source Provenance of Obsidian Artifacts from Mainly Archaic Contexts in the Tollgate and Tollhouse Canyon Region, Southeastern Arizona. UC Berkeley: Archaeological Research Facility. Report prepared for SWCA, Inc., Tucson, Arizona.
2	348	Site AZ CC:3:84	Arizona	2	1	2																Shackley, M.S. 2002. Source Provenance of Obsidian Artifacts from Mainly Archaic Contexts in the Tollgate and Tollhouse Canyon Region, Southeastern Arizona. UC Berkeley: Archaeological Research Facility. Report prepared for SWCA, Inc., Tucson, Arizona.
2	349	Site AZ CC:3:85	Arizona	1	1	1																Shackley, M.S. 2002. Source Provenance of Obsidian Artifacts from Mainly Archaic Contexts in the Tollgate and Tollhouse Canyon Region, Southeastern Arizona. UC Berkeley: Archaeological Research Facility. Report prepared for SWCA, Inc., Tucson, Arizona.
2	350	Site AZ CC:4:24	Arizona	2	2	1			1													Shackley, M.S. 2002. Source Provenance of Obsidian Artifacts from Mainly Archaic Contexts in the Tollgate and Tollhouse Canyon Region, Southeastern Arizona. UC Berkeley: Archaeological Research Facility. Report prepared for SWCA, Inc., Tucson, Arizona.
2	360	San Luis de Cabezon (LA 110946)	New Mexico	104	6			103					1									Shackley, M.S. 2014. Source Provenance of Obsidian Artifacts from the Dinwiddie Site (LA 106003), Cliff, Western New Mexico. UC Berkeley: Archaeological Research Facility. Report prepared for Archaeology Southwest, Tucson, Arizona.

Time Period	ID	Site	Modern State	N	# sources (all subsources)	TMC	AW	TJEM	CC	GC	LV	MDT	TMT	TMFVF	TSF	SF	SSM	ST	SUP	TANK	Unknown	Bib Source
2	361	The Hilltop Bison Site (LA 172328)	New Mexico	40	3			40														Shackley, M.S. 2014. Source Provenance of Obsidian Artifacts from the Dinwiddie Site (LA 106003), Cliff, Western New Mexico. UC Berkeley: Archaeological Research Facility. Report prepared for Archaeology Southwest, Tucson, Arizona.
2	362	Encino Wash/ MAPCO Project (LA 25673)	New Mexico	49	3			49														Shackley, M.S. 2014. Source Provenance of Obsidian Artifacts from the Dinwiddie Site (LA 106003), Cliff, Western New Mexico. UC Berkeley: Archaeological Research Facility. Report prepared for Archaeology Southwest, Tucson, Arizona.
2	372	AZ N:12:22	Arizona	1	1										1							Shackley, M.S. 1992. An Energy Dispersive X-Ray Fluorescence (EDXRF) Analysis of 10 Obsidian Artifacts from Two Prehistoric Sites Near Mayer, Arizona. UC Berkeley: Archaeological Research Facility. Report prepared for Archaeological Consulting Services, Tempe, Arizona.
2	373	AZ N:12:25	Arizona	9	4									2	6						1	Shackley, M.S. 1992. An Energy Dispersive X-Ray Fluorescence (EDXRF) Analysis of 10 Obsidian Artifacts from Two Prehistoric Sites Near Mayer, Arizona. UC Berkeley: Archaeological Research Facility. Report prepared for Archaeological Consulting Services, Tempe, Arizona.
2	386	Mescalero Cave (LA 11033)	New Mexico	5	2			5														Shackley, M.S. 2002. Source Provenance of Obsidian Artifacts from Mescalero Cave (LA 11033), Central New Mexico. UC Berkeley: Archaeological Research Facility. Report prepared for Office of Archaeological Studies, Museum of New Mexico, Sante Fe.
3	39	LA43766	New Mexico	4	2	2				2												Schriever, B. A., Shackley, M.S., and Taliaferro, M.S. 2010. Obsidian Procurement, Least Cost Path Analysis, and Social Interaction in the Mimbres Area of Southwestern New Mexico. Journal of Archaeological Science 37(2010): 536–548.
3	50	LA99631	New Mexico	25	6	19	1	3	1							1						Schriever, B. A., Shackley, M.S., and Taliaferro, M.S. 2010. Obsidian Procurement, Least Cost Path Analysis, and Social Interaction in the Mimbres Area of Southwestern New Mexico. Journal of Archaeological Science 37(2010): 536–548.
3	188	Las Capas (AZ AA:12:111 ASM)	Arizona	9	5	3											1	2	2	1		Shackley, M.S. 2011. Source Provenance of Obsidian Artifacts from Las Capas (AZ AA:12:111 ASM) and Los Pozos (AZ AA:12:91 ASM), Tucson Basin, Arizona. UC Berkeley: Archaeological Research Facility. Report prepared for Desert Archaeology, Inc.

Time Period	ID	Site	Modern State	N	# sources (all subsources)	TMC	AW	TJEM	CC	GC	LV	MDT	TMT	TMFVF	TSF	SF	SSM	ST	SUP	TANK	Unknown	Bib Source
3	189	Los Pozos (AZ AA:12:91 ASM)	Arizona	1	1						1											Shackley, M.S. 2011. Source Provenance of Obsidian Artifacts from Las Capas (AZ AA:12:111 ASM) and Los Pozos (AZ AA:12:91 ASM), Tucson Basin, Arizona. UC Berkeley: Archaeological Research Facility. Report prepared for Desert Archaeology, Inc.
3	333	Clearwater Site (AZ BB:13:6 (ASM))	Arizona	7	5	1					1				2					2	1	Thiel, J.H. and Mabry, J.B. eds. 2006. Rio Nuevo Archaeology Program, 2000–2003: Investigations at the San Agustin Mission and Mission Gardens, Tucson Presidio, Tucson Pressed Brick Company, and Clearwater Site. Technical Report No. 2004-11. Chapter 17: Sources of Obsidian Artifacts. Center for Desert Archaeology, Tucson, Arizona.
3	334	Tucson Presidio (AZ BB:13:13 (ASM))	Arizona	1	1															1		Thiel, J.H. and Mabry, J.B. eds. 2006. Rio Nuevo Archaeology Program, 2000–2003: Investigations at the San Agustin Mission and Mission Gardens, Tucson Presidio, Tucson Pressed Brick Company, and Clearwater Site. Technical Report No. 2004-11. Chapter 17: Sources of Obsidian Artifacts. Center for Desert Archaeology, Tucson, Arizona.
3		Tularosa Cave		1	1								1									
3		Cordova Cave		50	3	30			5	15												
3		O Block Cave		60	3	33			2	25										-		

Chapter 5

Changing Patterns of Obsidian Procurement in Highland Oaxaca, Mexico

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Abstract

Obsidian was a valued good throughout the prehispanic sequence in Oaxaca (Mexico). Yet, there is no obsidian source in the entire state of Oaxaca, and all archaeological obsidian recovered in the centrally situated Valley of Oaxaca was procured from locations that were at least 200km away. We draw on a large corpus of more than 20,000 sourced pieces of obsidian from prehispanic sites in Oaxaca to document dramatic shifts in networks of exchange over time. Obsidian was traded into Oaxaca, arriving at different entry points, through multiple routes that often were simultaneously active. Our findings do not support a model of centralized control or redistribution by urban Monte Albán or any other settlement. Obsidian assemblages in Oaxaca were affected by extra-regional, geopolitical processes that impacted broader networks of exchange.

Introduction

During the prehispanic era, the Valley of Oaxaca was a densely settled core region of Mesoamerica (Palerm and Wolf 1957). Monte Albán was the capital and largest urban center in the valley from the city's founding (*c.* 500 BC) until its decline more than 1300 years later (*c.* AD 750–850) (Blanton 1978). Monte Albán's scale and monumentality never was matched by any other settlement during the prehispanic era. Following the decline of Monte Albán, which was situated at the nexus of the valley's three arms, the eastern Tlacolula arm of the valley became the demographic and commercial center of the region, although a shift back toward the center was in process at the time of the European invasion (e.g., Kowalewski *et al.* 1989; Oudijk 2008). Here, drawing on variable patterns of obsidian procurement, we examine transitions in networks of long-distance interaction in this context of a shifting political landscape.

Since systematic archaeological research began in the Valley of Oaxaca (Bernal 1965), key questions have revolved around the nature of the relationships between the region's inhabitants with people elsewhere in Mesoamerica, including the Gulf Coast Olmec region during the Formative period (Blomster *et al.* 2005; Flannery *et al.* 2005; Pool 2009; Rosenswig 2010; Sharer *et al.* 2006), the Central Mexican metropolis, Teotihuacan, during the Classic period (Blanton *et al.* 1993: 88, 134; Winter 1998), and neighboring populations to the north and west in the Postclassic period during the so-called Mixtec invasion (Feinman and Nicholas 2016a; Paddock 1983). We cannot resolve these debates here. But we do take a necessary step to assess these relationships by looking at the diachronic movement of obsidian, a key good that was exotic but always valued in the region.

Obsidian, or volcanic glass, was highly prized for its sharp cutting edge. Obsidian implements are almost ubiquitous at prehispanic Mesoamerican sites, including in the Valley of Oaxaca, even though there are no obsidian sources in the entire state. In Mesoamerica, principal obsidian sources are found in only two broad volcanic bands, the Central-to-West Mexican Highlands, to the north, and the Guatemalan Highlands, to the southeast (Figure 5.1, Table 5.1), so all obsidian in the valley arrived through long-distance networks of exchange. Obsidian acquisition in the prehispanic Valley of Oaxaca was not dampened by the widespread local availability of other stone resources (including basalt, chert, and quartz) (Feinman *et al.* 2006; Parry 1987; Whalen 1986), all of which were modified into stone implements, albeit of varying quality and proficiency.

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Figure 5.1. Map of Mesoamerica showing location of principal obsidian sources, sites with well-dated sourced obsidian in Oaxaca, and other sites mentioned in the text. See Figure 5.2 for sites in the Valley of Oaxaca, the Sierra Norte, the Mixe region, and Nejapa.

Table 5.1. List of sources found at sites in highland Oaxaca

Macroregion	Code	Obsidian source	Zone
West	AV	Altotonga	Gulf Coast/Puebla
West	ZP	Zaragoza	Gulf Coast/Puebla
West	GP	Guadalupe Victoria	Gulf Coast/Puebla
West	PV	Pico de Orizaba	Gulf Coast/Puebla
West	MH	Malpaís	Central Mexico
West	PP	Paredón	Central Mexico
West	SH	Sierra de Pachuca	Central Mexico
West	TH	Tulancingo	Central Mexico
West	PH	Tepalzingo	Central Mexico
West	ZH	Zacualtipan	Central Mexico
West	OM	Otumba	Central Mexico
West	PM	Pacheco	Central Mexico
West	PQ	El Paraíso	Central Mexico
West	UM	Ucareo	West (Michoacán)
West	ZM	Zinapécuaro	West (Michoacán)
West	CZM	Cerro Negra	West (Michoacán)
West	CMJ	Magdalena	West (Jalisco)
East	CG	El Chayal	Guatemala
East	IG	Ixtepeque	Guatemala
East	SMJ	San Martín Jilotepeque	Guatemala

Until recently, little obsidian from archaeological contexts in the Valley of Oaxaca had been sourced. Jane Pires-Ferreira (1976) and Michael Elam (1993) analyzed small samples of Formative and Classic period obsidian assemblages and documented that a wide array of different sources, mostly from Central Mexico and the Gulf Coast/Puebla, but also from West Mexico and the Guatemalan Highlands, reached the Valley of Oaxaca. Nevertheless, their samples for any one site or time period were small, which limited the scope of interpretation based on the observed patterns. In this study we draw on more recent work that has increased the total sample of sourced obsidian from the Valley of Oaxaca and neighboring highland regions from around 500 to more than 23,000. Here, we examine temporal changes in the relative abundance of different sources to see how obsidian exchange networks shifted over time.

Obsidian is only one good that was exchanged across prehispanic Mesoamerica. But with a large sample of sourced obsidian, we have the potential to look at flows of goods and variability in exchange networks over time in ways that are not possible for any other archaeological material that was transferred in comparable volumes. Thus, obsidian may be employed as an oft-transferred good, in a sense a kind of proxy, for outlining relational links in interregional networks. Nevertheless, we recognize that the exchange path for other nonlocal goods may vary from that of obsidian. Was most obsidian in Oaxaca procured from the closest sources (approximately 200–250km from the center of the valley), or did extra-regional links shift across time, and, if so,

Table 5.2. Chronology and period designations

Period	Designation	Dates	Valley of Oaxaca
P1	Early Formative	~1600–1200 BC	Tierras Largas
P2	Early Formative	1200–900 BC	San José
P3a	Middle Formative	900–600 BC	Guadalupe
P3b	Middle Formative	600–300 BC	Rosario/Monte Albán Early I
P4a	Late Formative	300 BC–AD 1	Monte Albán Late I
P4b	Terminal Formative	AD 1–300	Monte Albán II
P5	Early Classic	AD 300–600	Monte Albán IIIA
P6	Late Classic	AD 600–900	Monte Albán IIIB-IV
P7	Early Postclassic	AD 900–1200	Early Monte Albán V
P8	Late Postclassic	AD 1200–1520	Late Monte Albán V

Table 5.3. Summary statistics for highland and valley sites

Statistics	P1	P2	P3a	P3b	P4a	P4b	P5	P6	P7	P8
Total number of valley sites	4	3	3	4	4	6	8	16	14	9
Total obsidian at valley sites	105	84	125	1131	603	1091	5599	10538	1655	926
Mean sample size	26	28	42	283	151	182	700	659	118	103
Median sample size	26	39	6	124	100	28	32	81	15	44
Total sources at valley sites	7	6	9	13	11	13	15	14	10	11
Valley sites with ≥5 sourced pieces	3	2	3	4	3	3	8	13	11	9
Average number of sources per site	3.7	5.0	4.3	8.0	7.7	9.3	5.4	7.7	4.3	4.2
Highest number at any one site	4	5	8	11	11	13	15	12	9	7

in what ways? Can we add new empirically grounded perspectives to longstanding debates regarding the valley's relations with other parts of Mesoamerica? Sourced obsidian assemblages also provide a means to examine relationships not only between the Valley of Oaxaca and other areas, but also within the valley itself, revealing the importance of different intraregional ties and networks over time and shedding light on temporal shifts in modes of transfer.

Sourcing Obsidian and the Oaxaca Sample

The properties that make obsidian a key material for studying exchange across time and space have been amply discussed (e.g., Braswell 2003; Cobean *et al.* 1991; Glascock 2002). Specifically, decades of research have identified a specific suite of trace elements that characterizes the composition of each source of obsidian, which allows individual archaeological pieces to be sourced to their point of origin through a number of available technologies that have been employed in archaeometric research—NAA (neutron activation analysis), ICP-MS (inductively coupled plasma mass spectrometry), and more recently, pXRF (portable X-ray fluorescence) (Glascock 2011; Glascock *et al.* 1998; Shackley 2011; Smith *et al.* 2007; Speakman *et al.* 2002).

We previously reported on subsets of sourced obsidian from the Valley of Oaxaca (Feinman *et al.* 2013, 2018), where we presented discussions of instrumentation and methods for source assignment; we have continued to use those methods for the larger sample of obsidian analyses reported here. In our laboratory analyses, the only limiting factor for sourcing is size of the piece, generally 1cm or larger in either length or width. For assemblages from the valley and neighboring areas analyzed by our facility, that resulted in sourcing between 60% and 90% of most collections, approximately 21,700 pieces. We added those data to other published or reported findings for highland Oaxaca (Blomster and Glascock 2010, 2011; Braswell 2003; Carpenter 2019; Elam 1993; Elam *et al.* 1992; Gendron *et al.* 2018; Konwest 2017; Pires-Ferreira 1976; Winter 1989; Workinger and King 2020; Zborover 2014). Although not a focus of this paper, analyzed obsidian from the Pacific Coast of Oaxaca (Hepp 2015; Joyce *et al.* 1995; Levine *et al.* 2011; Williams 2012; Workinger 2002) provides context for potential routes of exchange.

As with any large set of archaeological data that includes materials from a broad area and a range of time periods, there are issues to resolve concerning contemporaneity and sample representativeness. To compare obsidian assemblages diachronically, we divide the cumulated obsidian archive into broad 250–400-year time periods (Table 5.2). Although the sample is smallest for early periods (Table 5.3), we have increased the sample of sourced obsidian from highland Oaxaca so that we now are able to divide what had been two 600-year spans

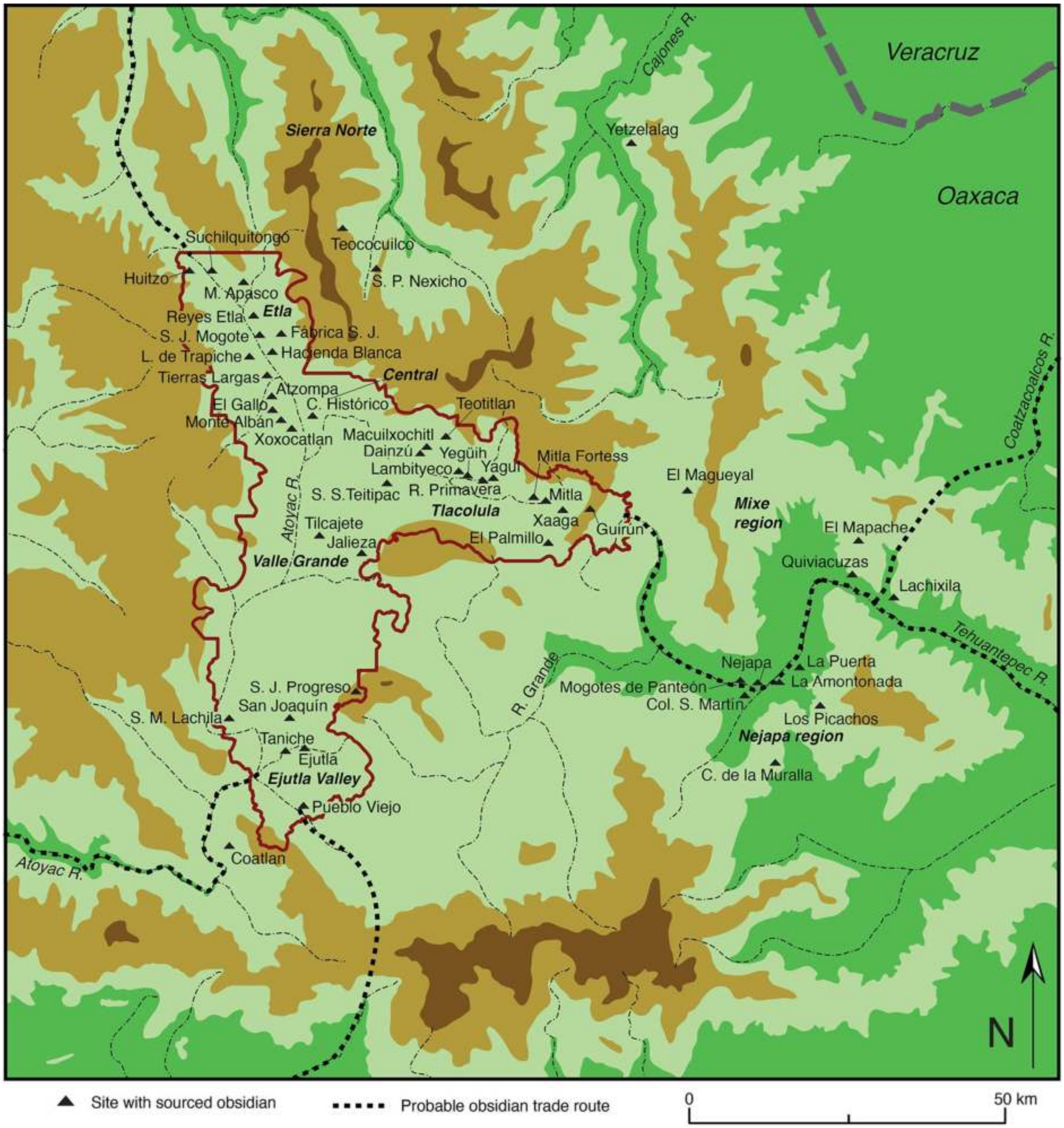

Figure 5.2. Map of highland Oaxaca showing sites with well-dated sourced obsidian and probable trade routes into the Valley of Oaxaca.

(P3 and P4) into 300-year periods. To avoid confusion with these prior publications (Feinman *et al.* 2019; Golitko and Feinman 2015), we retain the use of period numbers 1–8 and add a letter designation to the subdivided periods (P3a, P3b, P4a, P4b).

Our overall sample, however, including sourced obsidian from more than 50 sites, is somewhat patchy, both temporally and spatially, dependent on where archaeological research has been conducted and whether or not researchers have carried out their own sourcing projects or made their materials available to us or others. We do not have information on the form of all obsidian pieces in the archive, nor do we know what percentage of every obsidian assemblage was sourced. Although these lacunae constrain speculations on the quantities of obsidian that were transferred over time, there are clear patterns in obsidian procurement and changes in exchange networks over time, and that is our focus.

The nexus for this investigation is the Valley of Oaxaca, for which we have the largest sample of sourced obsidian (Figure 5.2). Smaller collections from neighboring areas—the Mixteca Alta, Sierra Norte, the Mixe region, and Nejapa—provide additional information and greater context for examining possible routes of exchange through which obsidian from different sources reached Oaxaca. The sample is largest for the Late Classic period in the Valley of Oaxaca, especially from sites where the first two authors excavated in the eastern, Tlacolula arm of the valley—El Palmillo, Mitla Fortress, Lambityeco—and the southern arm—Ejutla (Feinman and Nicholas 2004, 2012; Feinman *et al.* 2002, 2010, 2016). As a consequence, more detailed interpretations can be advanced for that temporal period.

Overall, obsidian from well-dated contexts in highland Oaxaca derived from 20 different geological sources (see Table 5.1), with significant variation over time in which obsidian sources dominated assemblages in the Valley of Oaxaca (Figure 5.3, Table 5.4). There was regular, but by no means total, procurement of obsidian from the closest outcrops. Obsidians from the Gulf Coast/Puebla (Pico de Orizaba, Guadalupe Victoria, Zaragoza) are most proximate, followed by Central Mexico (Otumba, Malpaís, Paredón, Sierra de Pachuca, Zacualtipan), West Mexico (Ucareo), and Guatemala (El Chayal, Ixtepeque, San Martín Jilotepeque). Of sources present in the highland Oaxaca sample, Orizaba is the closest, approximately 225km from the center of the Valley of Oaxaca. The two most distant sources are Magdalena in Jalisco and Ixtepeque in highland Guatemala, both ~800–900km away. Collectively, the three Guatemalan sources comprise several percent of the overall obsidian assemblage in the Valley of Oaxaca from the Early Formative (~1600 BC) through the Terminal Formative (~AD 300), after which they are much rarer (Figure 5.3, Table 5.4). For all periods, spatially variable patterns in the obsidian assemblages from the valley do not conform to the expectations of a model in which obsidian was procured centrally and then redistributed or parceled evenly to outlying localities. Rather, the specific movement of obsidian into the Valley of Oaxaca reflects exchange networks that shifted with political and economic transitions and the predominant modes of transfer across Mesoamerica.

Obsidian Procurement in the Highlands of Oaxaca

Early Formative Period (~1600/1500–900 BC)

From the time of the earliest sedentary villages in highland Oaxaca (P1, ~1600/1500–1200 BC), communities obtained obsidian from several different sources (Table 5.4, Table 5.5). Most of the obsidian that reached the Valley of Oaxaca and neighboring areas to the north (Mixteca Alta and Sierra Norte) was originally procured from Gulf Coast/Puebla sources, predominantly from Guadalupe Victoria (Figure 5.3), one of the sources closest to highland Oaxaca. Obsidian flakes from this source dominated the valley assemblages. The ~3% that arrived as prismatic blades were almost entirely from Central Mexican sources. Although blade technology was present in Mesoamerica by the Early Formative (e.g., Awe and Healy 1994; De León *et al.* 2009; Hirth *et al.* 2013; Jackson and Love 1991; Parry 1987), as in Oaxaca, blades were rare in most areas, including at contemporaneous San Lorenzo Tenochtitlán in the Gulf Coast, where only 6% of the assemblage consisted of blades, and most flakes also were from the Guadalupe Victoria source (Hirth *et al.* 2013: 2790). One of the closest sources to San Lorenzo is Guadalupe Victoria, a low-quality material readily available on the surface as cobbles. The material from this source is not suitable for making prismatic blades (Stocker and Cobean 1984).

By the latter half of the Early Formative (P2, 1200–900 BC), a variety of obsidians continued to reach highland Oaxaca (Table 5.3). In valley assemblages, there was a proportional shift away from Gulf Coast/Puebla sources to those from Central Mexico (Figure 5.3), most frequently from Otumba. In the Mixteca Alta, Paredón obsidian was most abundant (Table 5.5). The second most abundant obsidian in the valley was Ucareo, situated in Michoacán. All these sources are at least 100km more distant than Guadalupe Victoria. This change in source regions aligns with other material evidence that the valley's closest extra-regional ties shifted away from the Gulf Coast and toward Central Mexico at this time (Flannery and Marcus 1994).

After 1200 BC, the size of central places or head towns increased across highland Mesoamerica, including in the Basin of Mexico and the Mixteca Alta (Blomster and Salazar Chávez 2020; Feinman 1991; Flannery and Marcus 1994). Initially settled ~1500 BC in the northern arm of the Valley of Oaxaca, San José Mogote also greatly expanded in size after 1200 BC, dwarfing other settlements in the region (Blanton *et al.* 1993; Kowalewski *et al.* 1989: 72–73; Marcus and Flannery 1996: 106). The expansion of long-distance ties between Oaxaca and Central Mexico (Figure 8.3 in Feinman *et al.* this volume) also likely served to transfer obsidian from Ucareo (Michoacán) to the Valley of Oaxaca. The greater diversity, or richness (Nelson *et al.* 2011), of sources at Etlatongo in the Mixteca Alta (9 sources), including Otumba and Ucareo, hint at the route through which Central Mexican obsidians reached the Valley of Oaxaca through down-the-line networks of exchange (Feinman *et al.* this volume). Although Guadalupe Victoria was no longer the most abundant obsidian, flakes still dominated the obsidian assemblage from the Valley of Oaxaca (Parry 1987: 65).

Table 5.4. Sourced obsidian in the Valley of Oaxaca by period. See Table 5.1 for explanations of source abbreviations

Period	N	AV	ZP	GP	PV	MH	PP	SH	TH	PH	ZH	OM	PM	PQ	UM	ZM	CMJ	CG	IG	SMJ	unknown
1	105	--	1.0%	80.0%	5.7%	--	1.0%	1.0%	--	--	--	10.5%	--	--	--	--	--	1.0%	--	--	--
2	84	--	6.0%	16.7%	--	--	--	--	1.2%	--	--	36.9%	--	--	34.5%	--	--	1.2%	--	--	3.6%
3a	125	--	2.4%	13.6%	4.8%	--	25.6%	4.0%	2.4%	--	--	40.8%	--	--	3.2%	--	--	0.8%	--	--	2.4%
3b	1131	--	1.4%	6.5%	1.9%	1.0%	53.1%	6.3%	0.1%	--	0.2%	26.5%	--	--	1.0%	--	--	0.2%	0.1%	0.4%	1.4%
4a	603	0.2%	7.1%	34.2%	1.0%	0.5%	21.2%	23.5%	--	--	0.5%	5.1%	--	--	4.3%	--	--	0.8%	--	--	1.5%
4b	1092	0.5%	7.6%	26.9%	1.4%	0.1%	17.2%	35.0%	0.1%	--	0.1%	7.3%	--	--	2.4%	0.1%	0.2%	0.3%	--	--	0.9%
5	5605	0.2%	16.7%	3.7%	0.9%	0.1%	5.5%	64.5%	--	--	0.4%	5.7%	0.04%	0.1%	1.9%	--	0.1%	0.1%	--	0.02%	0.2%
6	10547	--	60.1%	2.3%	1.3%	0.02%	2.1%	14.9%	0.1%	0.01%	0.7%	4.9%	--	--	13.1%	--	--	0.1%	0.02%	0.01%	0.3%
7	1656	--	16.0%	0.4%	16.1%	0.1%	0.8%	60.4%	--	--	--	4.6%	--	--	1.2%	--	--	0.1%	0.1%	--	0.2%
8	986	--	15.2%	0.5%	18.4%	0.1%	0.1%	59.5%	--	--	0.5%	2.8%	--	0.1%	2.4%	--	--	0.1%	--	--	0.2%

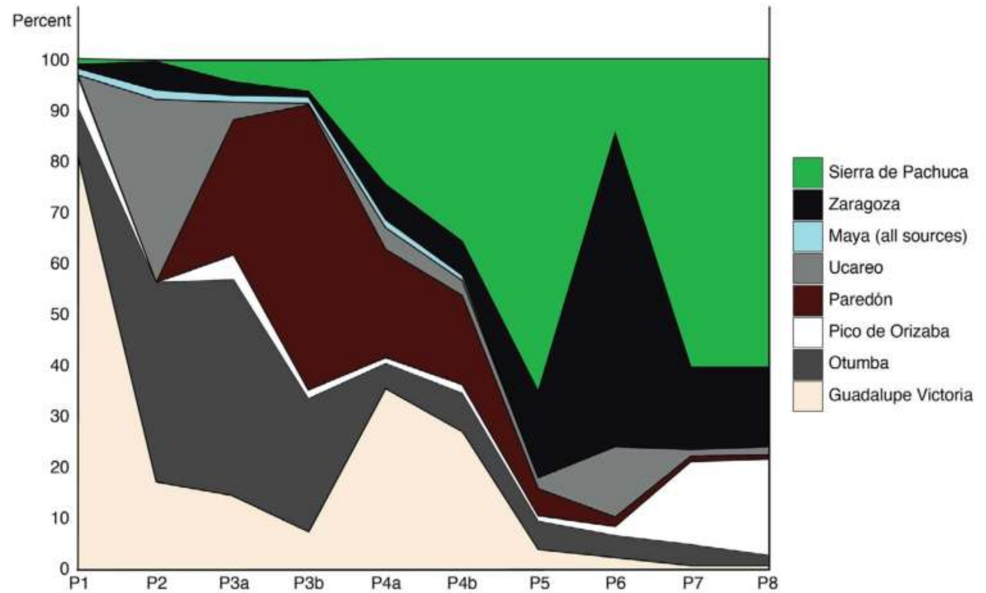

Figure 5.3. Sourced obsidian over time in the Valley of Oaxaca. Graph does not include sources that do not form at least 1% of the assemblage in at least one period (see Table 5.4 for full list of sources for each time period; see Table 5.1 for explanations of source abbreviations.).

Table 5.5. Sourced obsidian at Formative sites in highland Oaxaca, grouped by period and subregion

Zone	Period	# sites	N	AV	ZP	GP	PV	MH	PP	SH	TH	PH	ZH	OM	PM	PQ	UM	ZM	CZM	CMJ	CG	IG	SMJ	unknown
Valley-Central	1	2	53	--	1.9%	71.7%	1.9%	--	1.9%	1.9%	--	--	--	18.9%	--	--	--	--	--	--	1.9%	--	--	--
Valley-Etla	1	2	52	--	--	88.5%	9.6%	--	--	--	--	--	--	1.9%	--	--	--	--	--	--	--	--	--	--
Mixteca Alta	1	1	45	--	--	82.2%	15.6%	--	2.2%	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Sierra Norte	1	1	20	--	--	90.0%	5.0%	--	--	--	--	--	--	--	--	--	--	--	--	--	5.0%	--	--	--
Mixteca Alta	2	1	216	--	--	6.9%	0.9%	--	64.5%	--	0.9%	--	--	18.0%	--	--	6.0%	--	0.9%	--	0.9%	0.9%	--	--
Valley-Etla	2	2	45	--	6.7%	11.1%	--	--	--	--	--	--	--	42.2%	--	--	31.1%	--	--	--	2.2%	--	--	6.7%
Valley-Central	2	1	39	--	5.1%	23.1%	--	--	--	--	2.6%	--	--	30.8%	--	--	38.5%	--	--	--	--	--	--	--
Valley-Etla	3a	2	119	--	2.5%	14.3%	5.0%	--	26.9%	4.2%	2.5%	--	--	41.2%	--	--	1.7%	--	--	--	0.8%	--	--	0.8%
Valley-Central	3a	1	6	--	--	--	--	--	--	--	--	--	--	33.3%	--	--	33.3%	--	--	--	--	--	--	33.3%
Mixteca Alta	3b	1	110	--	2.7%	13.6%	2.7%	--	40.9%	5.5%	--	--	--	28.2%	--	--	5.5%	--	--	--	0.9%	--	--	--
Nejapa	3b	1	9	--	--	--	11.1%	--	66.7%	11.1%	--	--	--	--	--	--	11.1%	--	--	--	--	--	--	--
Valley-Central	3b	2	882	--	1.4%	6.2%	1.2%	0.9%	54.4%	3.2%	--	--	0.2%	28.9%	--	--	1.1%	--	--	--	0.1%	--	0.5%	1.8%
Valley–Valle Grande	3b	1	135	--	0.7%	6.7%	3.7%	0.7%	53.3%	20.0%	--	--	--	14.8%	--	--	--	--	--	--	--	--	--	--
Valley-Etla	3b	1	114	--	2.6%	7.9%	5.3%	1.8%	43.0%	14.0%	0.9%	--	--	21.9%	--	--	0.9%	--	--	--	0.9%	0.9%	--	--
Mixteca Alta	4a	1	22	--	9.1%	36.4%	36.4%	--	9.1%	9.1%	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Valley–Valle Grande	4a	1	100	--	--	80.0%	1.0%	--	1.0%	--	--	--	--	1.0%	--	--	13.0%	--	--	--	3.0%	--	--	1.0%
Valley-Etla	4a	1	3	--	--	--	--	--	33.3%	--	--	--	--	66.7%	--	--	--	--	--	--	--	--	--	--
Nejapa	4a	1	7	--	57.1%	--	14.3%	--	--	28.6%	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Valley-Central	4a	2	500	0.2%	8.6%	25.2%	1.0%	0.6%	25.2%	28.4%	--	--	0.6%	5.6%	--	--	2.6%	--	--	--	0.4%	--	--	1.6%
Mixteca Alta	4b	2	16	--	--	31.3%	43.8%	--	6.3%	18.8%	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Valley-W Tlacolula	4b	1	2	--	--	--	--	--	--	100.0%	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Valley-Central	4b	1	782	0.6%	9.7%	11.1%	0.4%	--	22.0%	43.7%	0.1%	--	0.1%	9.1%	--	--	2.3%	0.1%	--	0.3%	0.1%	--	--	0.3%
Valley-Etla	4b	2	56	--	--	14.3%	3.6%	--	19.6%	53.6%	--	--	--	7.1%	--	--	1.8%	--	--	--	--	--	--	--
Valley–Valle Grande	4b	2	251	--	2.8%	79.0%	4.0%	0.4%	2.0%	3.2%	--	--	--	2.0%	--	--	2.8%	--	--	--	0.8%	--	--	3.2%

Middle Formative (900–300 BC)

The Valley of Oaxaca continued to have strong connections with Central Mexico during the Middle Formative. Early in the period (P3a, 900–600 BC), the number of sources identified in valley assemblages increased to nine. Otumba continued to be the most frequent obsidian (Figure 5.3). Ucareo diminished in abundance, while Paredón, which previously had reached the Mixteca Alta in high quantities but had been rare in the valley, became the second most procured source.

Later in this era (P3b, 600–300 BC), Paredón further increased in abundance, surpassing Otumba across the Southern Highlands. These two sources dominated assemblages in the valley and the Mixteca Alta, with smaller amounts of another Central Mexican source, Sierra de Pachuca, at most sites. In Oaxaca, the closer, Gulf Coast/Puebla sources (Guadalupe Victoria and Zaragoza) continued to be present but in lower quantities.

Overall, the array of different sources found at valley sites increased to 13, and the average number of sources per site increased to 8, almost twice as many as in prior periods (Table 5.3). Other changes in obsidian procurement at this time are evident in pan-regional network graphs that illustrate a shift from more-linear regional networks in earlier periods (Figure 8.3 in Feinman *et al.* this volume) to more interconnected graphs (Figure 8.5 in Feinman *et al.* this volume). We see this change in network structure as indicative of a transition from elite-focused down-the-line routes of transfer to wider, more-interconnected networks that provided broader distributions of goods and so richer obsidian assemblages at more sites. The latter pattern conforms to expectations for networks of marketplace exchange (Feinman and Garraty 2010; Hirth 1998: 454–455, 2012; Renfrew 1975: 42; Stark and Garraty 2010). The structure of the networks, the greater volume of material, and the higher number of sources per node do not conform with modes of exchange limited to reciprocal, down-the-line transfers between householders. Based on other, different suites of empirical evidence and material distributions, the emergence of a market-based system of exchange has long been proposed for the Valley of Oaxaca, coincident with the establishment in ~500 BC of a new urban settlement, Monte Albán. That city rapidly grew to become the largest central place in the region, requiring new mechanisms of provisioning for its resident population (e.g., Feinman *et al.* 1984; Nicholas and Feinman 2022; Winter 1984).

Although prismatic blades were becoming as or more abundant than flakes in obsidian assemblages elsewhere in Mesoamerican during the Middle Formative (e.g., Clark 1987; Hirth 2012; Hirth *et al.* 2013), they were not yet reaching the Valley of Oaxaca in large numbers. Flakes continued to be the dominant tool form (~90%), with the highest quantities from Paredón and Otumba. The only obsidian source for which blades were more abundant than flakes was Pachuca, although the quantities were low.

Late/Terminal Formative (300 BC–AD 300)

During the Late/Terminal Formative, the same overall suite of sources was acquired by the residents of the Valley of Oaxaca, but in different proportions that reflect expanding exchange networks. The total number of different sources that reached the valley was 11 (Late Formative) and 13 (Terminal Formative), with site averages remaining high (Table 5.3). A key dimension of variation is between the main hill at Monte Albán, where the Main Plaza is situated, compared to the rest of the valley. From its foundation ~500 BC until its decline at the end of the Classic period, Monte Albán obtained most of its obsidian from Central Mexican sources (Figure 5.4a) in contrast to other parts of the valley where Gulf Coast/Puebla sources tended to be more prevalent (Figure 5.4b).

During the Late Formative (P4a, 300 BC–AD 1), obsidian from Gulf Coast/Puebla sources (mostly Guadalupe Victoria and Zaragoza) again reached highland Oaxaca in significant quantities, likely entering the valley from the east (Figure 5.3). The Gulf/Puebla sources largely replaced Paredón at most valley sites, including an outlying, lower precinct of Monte Albán (Figure 5.4b). At the monumental center of Monte Albán, however, Central Mexican sources continued to dominate the assemblage, notably Paredón and Sierra de Pachuca, but not to the extent they had previously, as the urban center also received slightly more obsidian from the Gulf (Figure 5.4a). Obsidian from Paredón was still mostly flakes, while Pachuca obsidian consisted mostly of blades. Although the overall proportion of blades in valley assemblages increased at this time, the change was greatest on Monte Albán's main hill, where blades increased to ~35% of the assemblage compared to less than 25% elsewhere in the valley.

These trends in obsidian procurement largely continued into the Terminal Formative (P4b, AD 1–300). Central Mexican obsidians continued to dominate the assemblage at Monte Albán, with Sierra de Pachuca arriving in ever larger quantities, accounting for more than 40% of all sourced obsidian at the site and ~70% of the blades. Blades overall increased to ~45% of the assemblage at Monte Albán as well as at other settlements in the northern arm of the valley. Yet settlements elsewhere in the valley continued to

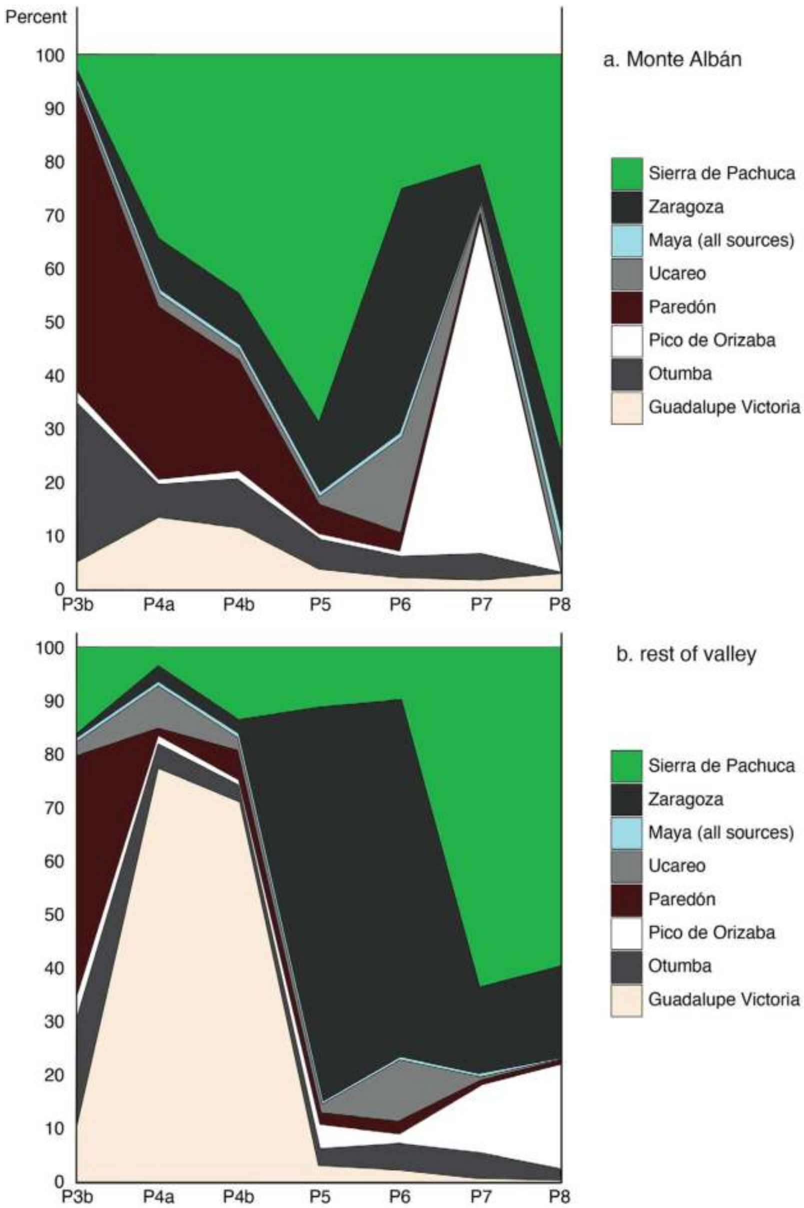

Figure 5.4a–b. a. Sourced obsidian over time on the main hill at Monte Albán.
b. Sourced obsidian over time in the Valley of Oaxaca, excluding the main hill at Monte Albán.

procure higher proportions of obsidian from Guadalupe Victoria, mostly in the form of flakes.

The diversity, or richness (Nelson *et al*. 2011), of obsidians reaching the Valley of Oaxaca, the increasing proportion of blades in valley assemblages, especially at Monte Albán, and the high average number of sources per site (9.3) toward the end of the Formative period hint at a change from earlier regional networks of marketplace exchange to higher volumes of flows between marketplaces, thereby transcending regional topographic limits. These greater connectivities likely were one factor in the procurement of obsidian from the distant Magdalena source in Jalisco by Monte Albán during the Terminal Formative and Early Classic periods (Tables 5.5 and 5.6). Monte Albán expanded its sphere of external relations at this time (Blanton *et al.* 1993; Kowalewski *et al.* 1989), thereby fostering connections with Teotihuacan, the growing Central Mexican metropolis that heavily utilized nearby obsidian sources, including Otumba and Sierra de Pachuca (e.g., Carballo 2013; Carballo *et al.* 2007). But given the spatial variability in Valley of Oaxaca assemblages, both in sources and tool forms, it is unlikely that Monte Albán's inhabitants directly controlled the import of or redistribution of centrally pooled obsidian to other contemporaneous communities. Even as Monte Albán's political hegemony was expanding (Spencer 2010), the

Table 5.6. Sourced obsidian at Classic and Postclassic sites in highland Oaxaca, grouped by period and subregion

Zone	Period	# sites	N	AV	ZP	GP	PV	MH	PP	SH	TH	PH	ZH	OM	PM	PQ	UM	ZM	CZM	CMJ	CG	IG	SMJ	unknown
Mixe	5	1	2	--	100.0%	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Nejapa	5	1	1	--	100.0%	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Mixteca Alta	5	2	105	--	13.3%	6.7%	3.8%	--	15.2%	32.4%	--	--	2.9%	15.2%	--	--	9.5%	--	--	--	--	--	1.0%	--
Valley-Ejutla	5	1	5	--	--	20.0%	--	--	--	80.0%	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Valley-Central	5	1	5204	0.2%	12.3%	3.8%	0.6%	0.1%	5.7%	68.7%	--	--	0.3%	5.9%	0.0%	0.1%	1.9%	--	--	0.1%	0.1%	--	0.0%	0.2%
Valley-W Tlacolula	5	2	38	--	71.1%	--	7.9%	--	--	18.4%	--	--	2.6%	--	--	--	--	--	--	--	--	--	--	--
Valley-E Tlacolula	5	3	303	--	76.7%	2.3%	2.6%	--	2.9%	9.7%	--	--	1.0%	3.2%	--	--	1.6%	--	--	--	--	--	--	--
Valley–Valle Grande	5	1	49	--	67.3%	8.2%	12.2%	--	--	4.1%	--	--	--	6.1%	--	--	2.0%	--	--	--	--	--	--	--
Mixe	6	3	220	--	86.2%	--	5.8%	--	0.9%	0.4%	--	--	--	0.9%	--	--	5.8%	--	--	--	--	--	--	--
Nejapa	6	1	2	--	100.0%	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Mixteca Alta	6	1	21	--	9.5%	14.3%	--	--	--	23.8%	--	--	--	19.0%	--	--	33.3%	--	--	--	--	--	--	--
Valley-Central	6	4	4106	--	47.7%	4.0%	0.8%	--	3.7%	23.1%	0.0%	--	0.5%	3.4%	--	--	16.1%	--	--	--	0.1%	0.0%	0.0%	0.4%
Valley-Ejutla	6	3	1862	--	52.1%	2.4%	1.3%	--	1.8%	8.4%	--	--	1.1%	5.2%	--	--	27.5%	--	--	--	--	--	--	0.2%
Valley-Etla	6	3	43	--	11.6%	2.3%	2.3%	--	27.9%	39.5%	--	--	--	14.0%	--	--	2.3%	--	--	--	--	--	--	--
Valley-W Tlacolula	6	1	1008	--	74.8%	0.7%	4.5%	--	1.6%	8.7%	0.1%	0.1%	0.3%	5.7%	--	--	3.2%	--	--	--	0.1%	--	--	0.3%
Valley-E Tlacolula	6	3	3357	--	76.3%	0.3%	1.0%	0.1%	0.3%	9.2%	0.2%	--	0.9%	6.1%	--	--	5.2%	--	--	--	0.2%	0.0%	--	0.2%
Valley–Valle Grande	6	2	162	--	50.9%	6.7%	1.2%	--	0.6%	32.5%	0.6%	--	1.2%	4.3%	--	--	1.8%	--	--	--	--	--	--	--
Mixe	7	4	296	--	87.2%	--	5.7%	--	--	1.4%	--	--	0.3%	--	--	--	5.4%	--	--	--	--	--	--	--
Nejapa	7	7	273	--	7.3%	--	75.1%	--	--	7.3%	--	--	0.4%	0.7%	--	--	--	--	--	--	7.3%	--	1.5%	0.4%
Sierra Norte	7	3	17	--	--	23.5%	11.8%	--	--	64.7%	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Valley-Central	7	2	111	--	7.2%	1.8%	63.1%	--	1.8%	18.9%	--	--	--	6.3%	--	--	0.9%	--	--	--	--	--	--	--
Valley-Ejutla	7	2	33	--	48.5%	--	--	--	--	24.2%	--	--	--	3.0%	--	--	24.2%	--	--	--	--	--	--	--
Valley-Etla	7	2	26	--	7.4%	--	11.1%	--	25.9%	40.7%	--	--	--	11.1%	--	--	3.7%	--	--	--	--	--	--	--
Valley-W Tlacolula	7	2	5	--	40.0%	--	--	--	--	60.0%	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Valley-E Tlacolula	7	5	1462	--	15.4%	0.3%	13.1%	0.1%	0.3%	65.3%	--	--	--	4.3%	--	--	0.7%	--	--	--	0.1%	0.1%	--	0.3%
Valley–Valle Grande	7	1	18	--	66.7%	--	11.1%	--	--	11.1%	--	--	--	11.1%	--	--	--	--	--	--	--	--	--	--
Mixteca Alta	8	5	142	--	7.0%	--	21.1%	--	0.7%	52.1%	--	--	2.8%	16.2%	--	--	--	--	--	--	--	--	--	--
Nejapa	8	4	91	--	1.1%	--	5.6%	--	1.1%	87.8%	--	--	--	4.4%	--	--	--	--	--	--	--	--	--	--
Sierra Norte	8	1	63	--	11.1%	1.6%	23.8%	--	--	36.5%	--	--	4.8%	3.2%	--	--	19.0%	--	--	--	--	--	--	--
Valley-Central	8	2	116	--	3.4%	0.9%	3.4%	0.9%	0.9%	88.8%	--	--	--	--	--	--	0.9%	--	--	--	0.9%	--	--	--
Valley-Ejutla	8	1	80	--	1.3%	1.3%	63.8%	--	--	31.3%	--	--	--	--	--	--	--	--	--	--	--	--	--	2.5%
Valley-Etla	8	2	61	--	--	1.6%	14.8%	--	--	77.0%	--	--	--	4.9%	--	--	1.6%	--	--	--	--	--	--	--
Valley-W Tlacolula	8	1	128	--	--	--	63.6%	--	--	34.1%	--	--	--	2.3%	--	--	--	--	--	--	--	--	--	--
Valley-E Tlacolula	8	2	541	--	25.7%	0.2%	3.7%	--	--	64.2%	--	--	0.4%	3.7%	--	0.2%	1.9%	--	--	--	--	--	--	--

center did not directly control obsidian exchange; some parts of the valley maintained closer ties and economic networks to eastern Puebla and the Gulf Coast.

Classic Period (AD 300–900)

During the Early Classic period (P5, AD 300–600) in the Valley of Oaxaca, consumption patterns again shifted for obsidian. Expanded exchange links brought obsidian from 15 different sources into the valley (Table 5.3). Beyond Monte Albán, Gulf Coast/Puebla sources continued to dominate valley assemblages, but Guadalupe Victoria was largely absent, while obsidian from Zaragoza became the dominant source at most sites (Figure 5.4b, Table 5.6). In contrast, Central Mexican sources continued to be most prevalent at Monte Albán, especially Pachuca (Figure 5.4a), most as blades. Across the valley, blades now accounted for 90–98% of obsidian assemblages. The increasing number of sources, blades, and overall quantities of obsidian in assemblages across the valley indicate that the valley was much more intensively connected into pan-regional exchange networks by the Early Classic. Two of us (Feinman and Nicholas 2020) have argued for greater cross-regional synchronization of marketplace exchange networks at this time, which would have facilitated greater interregional connectivity. Still, Monte Albán did not centrally control the economic networks that brought a range of goods to the region; these networks were largely independent of the urban center's expanding regional political hegemony (Kowalewski *et al.* 1989).

Monte Albán is thought to have had a special relationship with Teotihuacan (Marcus 1983; Millon 1973). The Central Mexican metropolis is located near several obsidian sources, including the Pachuca source of green obsidian, which was the dominant obsidian at Monte Albán in the Early Classic period, when Teotihuacan was the largest, most important center in the highlands. Although Otumba is the source closest to Teotihuacan (~15km), Pachuca (~48km) became the dominant obsidian at the site at this time (Hirth *et al.* 2019).

One material that Teotihuacan's populace sought from Oaxaca is mica, most of which is concentrated in two residential compounds related to representatives of the urban center's governing elite. Based on sourcing analyses, the mica was largely derived from Ejutla in the southern part of the Valley of Oaxaca (Manzanilla *et al.* 2017: 36). During the Early Classic, the Ejutla Valley was closely tied into the Monte Albán polity (Feinman and Nicholas 2013: 96), a relationship that is visible in the obsidian network graphs (see Figure 8.8 in Feinman *et al.* this volume). The obsidian assemblage at the principal Early Classic center in Ejutla, though small, also was dominated by Pachuca obsidian, which could have been exchanged through the networks that also moved mica. The presence of mica from Oaxaca in elite contexts at Teotihuacan, together with the high proportion of Central Mexican obsidian at Monte Albán when most other sites in the valley had much less of this material, provides a basis to propose that select transfers may have occurred through special elite channels.

For the rest of the Valley of Oaxaca, including the eastern, Tlacolula arm, there was a stronger relationship with Puebla and the Gulf Coast during the Early Classic (see Figure 8.8 in Feinman *et al.* this volume). Cantona, in eastern Puebla, was beginning to become an important center that competed with but was still overshadowed by Teotihuacan (García Cook and Merino Carrión 1998: 213). Very little obsidian from sources near Teotihuacan is found at Cantona (García Cook and Merino Carrión 1998: 214). Instead, Cantona exploited the nearby Zaragoza source; material from that source was exchanged with other regions, including the Valley of Oaxaca, and became the dominant obsidian in Tlacolula and the Valle Grande. The stark differences in the obsidian assemblages at Monte Albán compared to other contemporaneous sites in the valley do not support the hypothesis that Monte Albán controlled or monopolized the import of obsidian and redistributed it to other communities in the valley (Figures 5.4a and 5.4b). Instead, obsidian appears to have entered the Valley of Oaxaca through several different exchange routes that were simultaneously active, with obsidian from diverse sources tending to enter the valley from different directions.

During the Late Classic period (P6, 600–900 BC), obsidian consumption patterns in the valley continued to shift. The relative amounts of Central Mexican obsidians that reached the Valley of Oaxaca declined from their peak in the Early Classic (Figure 5.3). Most of this decline occurred at Monte Albán, where Pachuca was no longer the most abundant source (Figure 5.4a). In the rest of the valley, obsidian from Gulf Coast/Puebla sources, principally Zaragoza, continued to dominate (Figure 5.4b). These changes appear to have been linked to the fall of Teotihuacan before ~AD 650 (Cowgill 2015). At the same time Cantona became the largest urban center in the Central Highlands (García Cook 1994, 2017: 22; García Cook and Merino Carrión 1998).

The Zaragoza source, only 7km away, may have been an important resource for the inhabitants of Cantona. Most of the obsidian at Cantona is from Zaragoza, and there are Cantona-like ceramics at many workshops at that source (García Cook 2003: 315, 339). Pottery and other goods from regions as far away as Oaxaca, Central Mexico, the Gulf Coast, and the Yucatán Peninsula also have been found at Cantona, indicating long-distance exchange connections (García Cook and Merino Carrión 1998: 213). During the Late Classic period, Zaragoza obsidian was exchanged across a wide area, with high quantities reaching Oaxaca, the southern Isthmus, the Gulf Coast, and across Puebla (Plunket and Uruñuela 2005: 105). Not only did Zaragoza obsidian continue to dominate assemblages in the Valley of Oaxaca, especially in the eastern, Tlacolula arm, but it now was also well represented at Monte Albán (Figure 5.4a).

In concert with increasing amounts of Zaragoza obsidian, there were other indications of links to Veracruz/Gulf Coast in Oaxaca (e.g., imitation fine orange pottery), especially in the eastern, Tlacolula arm (Feinman and Nicholas 2013: 137; Kowalewski *et al.* 1989: 253–254). A principal travel route into the valley during the Late Classic entered the Tlacolula arm from the east, connecting the valley to the Gulf Coast (see Figure 5.2). During the Late Classic period, the Gulf Coast region was a nexus for wide-ranging networks that also brought Central and West Mexican obsidian to the northern Yucatán Peninsula (Feinman *et al.* 2019; Golitko and Feinman 2015). This connection to the Gulf Coast may have been an important factor that contributed to the rise of the Tlacolula arm of the valley as the new demographic and commercial center of the valley with the decline of Monte Albán by the end of the Classic period (Feinman 2006; Feinman and Nicholas 2013, 2017).

The variability of the obsidian assemblages in different parts of the Valley of Oaxaca during the Late Classic period indicate that the inhabitants of these sectors participated in different, albeit interconnected, networks of exchange. Three primary routes for obsidian procurement can be defined (Figure 5.2). Gulf Coast/Puebla obsidian largely entered the eastern arm of the valley. Dominance of Zaragoza obsidian in assemblages generally decreases from east to west in the valley (Table 5.6). We also sourced obsidian at several sites in the Mixe area east of the valley that are situated adjacent to an important, historically known trade route to the Gulf Coast. In one Late Classic context at Lachixila, 99% of obsidian blades are from Zaragoza.

In contrast, Central Mexican obsidian, especially Pachuca, formed a larger proportion of the assemblage at sites in the northern, Etla arm of the valley, generally decreasing with distance to the south and east; there was almost no Central Mexican obsidian in the Mixe area, near the eastern route. Although Pachuca was a less important source immediately after the fall of Teotihuacan, Central Mexican obsidian continued to enter the valley from the north.

Obsidian from West Mexican sources generally was never as abundant in the valley as Central Mexican or Gulf Coast sources were. Yet during the Late Classic period in Ejutla at the southern end of the valley, 28% of the assemblage was Ucareo obsidian, even though Ejutla is more distant (as the crow flies) from the Ucareo source than the northern or central parts of the valley are (Table 5.6). The high percentages of Ucareo obsidian at Late Classic sites on the southern coast of Oaxaca and in the Mixteca Alta to the northwest evidence a route that skirted west of Central Mexico and the Valley of Oaxaca and arrived in the Ejutla Valley from the south or west.

During the Classic period, craft specialists at Ejutla fashioned large quantities of ornaments from marine shell, most of which was procured from the Pacific Coast of Oaxaca and was intended for exchange beyond the local community (Feinman and Nicholas 1995, 2000, 2004). An abundance of heavily worn obsidian blades, possibly used in working the shell, was associated with the shell debris. It seems probable that the West Mexican obsidian moved into Ejutla from the south or west along with Pacific Coast shell. Although shell working is rare in the Oaxaca highlands, there is another prehispanic shell-working site, also with lots of obsidian (unfortunately not sourced), in the Miahuatlán Valley south of Ejutla (Brockington 1973; Markman 1981). These materials may have moved along similar routes to both sites (Ball and Brockington 1978).

Through these multiple routes, obsidian from a large number of sources (14) continued to reach the Valley of Oaxaca, traded via extensive marketplace networks that brought diverse sets of obsidian to consumers. During Monte Albán's hegemony (*c.* 500 BC–AD 850) as the region's preeminent central place, the average number of sources per site was higher than either before its foundation or after its decline (Table 5.3). But throughout this era, the assemblages were never uniform either across space or over time. There not only were subregional differences in obsidian assemblages but also variation among houses at individual sites (Feinman *et al.* 2013). Although we do not have the same level of detail for Monte Albán, from the samples we have sourced and from those reported in other publications (Elam 1993; Elam *et al.* 1992), obsidian assemblages varied across the site in Late Classic contexts, with Pachuca more abundant at the north end of the Main Plaza, Zaragoza more prevalent elsewhere on the main hill and in the Atzompa sector to the north, and Ucareo present mostly in southern parts of the hill. Located at the hub of the valley, Monte Albán consumed obsidians that entered the region from different gateways.

Postclassic Period (AD 900–1520)

During the Classic–Postclassic transition, new exchange networks formed in response to the rise of new power centers as the earlier regional states disintegrated (see Figures 8.9 and 8.10 in Feinman *et al.* this volume; see also Braswell 2003). Obsidian assemblages in the Valley of Oaxaca during the Early Postclassic period (P7, AD 900–1300) were greatly affected by the resultant disruption in trade networks, and the diversity of sources present in the valley decreased to ten, and the average number of sources per site fell to 4.3 (Table 5.3). With the fall of Cantona after *c.* AD 850 (García Cook and Merino Carrión 1998: 213) and the loss of networks of exchange associated with that city, Zaragoza was no longer the most prevalent obsidian in most of the Valley of Oaxaca, and the Central Mexican Pachuca source became the dominant source (Figure 5.3), although its distribution was variable, accounting for as much as 67% of the assemblage at some sites and as little as 11% at others.

As Zaragoza decreased in relative abundance, another Gulf Coast/Puebla source, Pico de Orizaba, began to reach the valley in quantities comparable to Zaragoza. This source had not been heavily traded to highland Oaxaca before (Table 5.6). But like the Pachuca source, sites procured these obsidians in widely different proportions. In a stark change from the Late Classic, either Pachuca or Pico de Orizaba, but not both, tended to be the dominant source at most sites in the Tlacolula arm, while Zaragoza continued to be an important source in Ejutla and the southern part of the valley. Pico de Orizaba replaced Pachuca as the dominant source at Monte Albán and other sites in the center of the valley. These patterns, and the lower average number of sources per site, reflect the disruption of marketplace networks that had existed during Monte Albán's hegemony. As the region's primary center declined, new exchange networks were forged (Feinman and Nicholas 2013, 2016b) that were perhaps similar to the more linear transfer links that had existed prior to Monte Albán's foundation. After Monte Albán, political fragmentation may have constrained the openness of market networks.

During the Late Postclassic period (P8, AD 1200–1520), population expansion and political change, ultimately centered on Tenochtitlan, led to the growth of Central Mexican demographic, political, and economic links to the south (e.g., Beekman and Christensen 2003; Pohl 2003). At the same time, Mesoamerica became more commercialized and was characterized by greater intensities of commodity movement than ever before (Blanton and Fargher 2012; Blanton *et al.* 2005; Blanton and Feinman 1984; Smith and Berdan 2000, 2003), as new socioeconomic routes and relations were forged (Smith and Berdan 2000: 284). In the Valley of Oaxaca, the number of sources of imported obsidian increased to 11. Pachuca continued to be the principal source overall, while at many sites Pico de Orizaba largely surpassed Zaragoza (Figure 5.3). As in the Early Postclassic, there still was considerable variability in obsidian assemblages between sites, even in the same subregion of the valley. Pachuca once again was the preeminent source at Monte Albán, in Etla, at several sites on the north side of Tlacolula, at San Pedro Nexicho in the mountains north of that arm, and in the Nejapa area to the east (Figure 5.2). In contrast, Pico de Orizaba was a more important source at other sites in Tlacolula and in Ejutla (Table 5.6). At the same time, Zaragoza remained a key, although not dominant, source at several sites in Tlacolula. These patterns at the scale of Oaxaca correspond with diverse routes of pan-regional exchange evident in the widespread distribution of Pachuca and other Mexican obsidians to the south and east across Mesoamerica (Braswell 2003; Feinman *et al.* 2019; Gasco 2017; Golitko and Feinman 2015).

Conclusions

Throughout the prehispanic era, obsidian was traded widely in Mesoamerica. Distance from source was always one important factor affecting obsidian assemblages, with sites close to obsidian sources often heavily exploiting them, not only for their own use but also as goods suitable for exchange. For the Valley of Oaxaca, however, far from any known obsidian source, distance from source was rarely, if ever, the predominant factor. At the same time, throughout the sequence, more obsidian from Gulf Coast/Puebla and Central Mexican sources entered the valley than from more distant West Mexican or Guatemalan sources. But across those broad expanses, the sources closest to the Valley of Oaxaca were not consistently procured in higher quantities. Over time there were significant changes in which sources were most abundant in the Valley of Oaxaca, from Guadalupe Victoria and Paredón in the Early Formative to Zaragoza and Pachuca during the Classic period to Pachuca and Orizaba during the Postclassic period. Changes in external geopolitical and economic circumstances impacted which obsidians most readily entered the Valley of Oaxaca. As a result, obsidian assemblages in Oaxaca were at least partially tied to the rising or falling fortunes of the inhabitants of large centers such as Teotihuacan, Cantona, and Tenochtitlan that were located near principal obsidian outcrops in the Central Highlands of Mexico and the relations that people at those sites had to the inhabitants of Oaxaca.

The great richness in obsidian assemblages at individual sites in the Valley of Oaxaca points to the presence of a range of distinct exchange networks that were not centered on Monte Albán. Before Monte Albán, trade networks tended to be based on linear, down-the-line networks, but when the new capital was established *c.* 500 BC, exchange networks shifted to accommodate higher flows of goods both locally and regionally (Feinman *et al.* this volume; Nicholas and Feinman 2022). The earliest obsidian reaching the valley was mostly flakes, but as transfer connections strengthened to other highland regions, especially Central Mexico, more blades began to be traded to the valley, first to Monte Albán in the Late and Terminal Formative, then more broadly across the valley by the Early Classic. Oaxaca was not near any local source, so distance from obsidian sources helps account for why blades did not become the dominant tool form in Oaxaca until later than in other Mesoamerican regions. At the same time, shifts in modes of exchange and the extent of interregional connectedness provide a basis to understand why blades reached the region in quantity when they did.

During its history, there is no evidence that Monte Albán directly controlled the regional import of obsidian, nor did the occupants of that site redistribute it to other communities in the valley. Through most of its history, Monte Albán's obsidian assemblage did not match that of any contemporaneous settlement in Oaxaca where we have sourced obsidian. Through its relationship with Teotihuacan during the Classic period, Monte Albán received much more obsidian from Central Mexico; at the same time the rest of valley, especially eastern Tlacolula, had stronger connections with Puebla and the Gulf Coast. Tlacolula continued to have closer ties to the east during the Postclassic period, even as Central Mexican obsidian again increased in northern and central parts of the valley as Aztec influences increasingly spread to the south. The strong ties to Veracruz and eastern Puebla may have been one important factor in the rise of eastern Tlacolula as the new demographic and commercial center of the valley during the Early Postclassic period. During Monte Albán's hegemony, valley residents in general obtained richer assemblages of obsidian than they did either before or after Monte Albán. The necessity of provisioning the large city may have been one important factor in the strength of the marketplace exchange networks that emerged along with the new urban center, and the city's residents were not the only ones affected.

We recognize that obsidian is only one good that moved in long-distance exchange networks across Mesoamerica. But it is presently the most useful class of artifacts for tracing the evident dynamism of the ancient Mesoamerican economy. By expanding the sample of sourced prehispanic obsidian from highland Oaxaca from 500 to more than 23,000 pieces, we have enhanced our perspective on the movement of goods into Oaxaca. Of course, the expansion of this sample to include obsidian from a broader range of sites would further amplify our understanding, and we continue to work toward that goal.

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Chapter 6

Instrument Source Attributions of Obsidian Artifacts from Tikal, Guatemala

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Abstract

I summarize and discuss a sample of 2435 artifacts from the Southern Lowland Maya site of Tikal, which were made of obsidian attributed to geological source by instrument. The sample includes 2387 attributions made by portable X-ray fluorescence at the Field Museum's Elemental Analysis Facility in 2010–2011 and 48 attributions made earlier by neutron activation analysis and X-ray fluorescence. The identification of 13 geological sources in Highland Guatemala and Central Mexico testify to Tikal's participation in an extensive, changing interregional pre-Columbian interaction sphere comprising regional networks determined by social network analysis. Additionally, the considerable explanatory potential of large-scale pXRF attributions is evident when geological sources are considered in relation to cultural variables, such as artifact type, recovery context, type of structure group, site zone, and date.

Preface

When I began working at Tikal in the 1960s, chemical analysis by instrument of archaeological materials had finally gotten underway in the Maya area, but it was expensive and time-consuming and often destructive of the analyzed object. "One day," I fantasized, as I sorted, counted, and catalogued hundreds of pieces of obsidian and wondered where they had come from, "someone will invent a hand-held device into which one can drop a piece of obsidian, press a button, and instantly and non-destructively identify its geological source." At the moment pXRF is the closest we've come to creating such a device, and now we should work out ways to make the best use of it.

Introduction: The Contributions of pXRF

In 2010 the Field Museum's Elemental Analysis Facility (EAF) attributed a large sample of obsidian artifacts from Tikal to geological source by portable X-ray fluorescence (pXRF). The EAF analyzed 2387 artifacts, which significantly advanced our understanding of the procurement and use of this culturally important material, all of which had to be brought to the city over considerable distances (Figure 6.1). We could add 48 source attributions that had previously been made by XRF and neutron activation analysis (NAA) (Moholy-Nagy *et al.* 1984; Moholy-Nagy *et al.* 2013; Moholy-Nagy and Nelson 1990) for a total of 2435 attributions. We published our work (Moholy-Nagy *et al.* 2013) and posted the paper together with its unprinted supplemental tables on academia.edu. Here we will summarize and discuss those results.

Generally, the pXRF attributions confirmed our conceptions about the procurement and use of obsidian at Tikal through time and over space during the Preclassic and Classic periods (Table 6.1). There were also some interesting new findings, which, in turn, suggest productive topics for future research.

Obsidian sources showed some correlations with artifact type. In particular, the predominance of El Chayal obsidian in the prismatic blade and ceremonial lithics industries suggests a supra-household level for the organization and administration of El Chayal obsidian procurement, possibly by the elite.

Obsidian artifacts were widely distributed among all social ranks, as assessed by residences and associated material culture.

Obsidian from Central Mexican sources apparently did not carry a higher social value than Guatemalan obsidians.

Obsidian artifact frequencies and diversity diminished towards the city peripheries, regardless of social rank, suggesting distribution through marketplace exchange.

Artifacts made of Central Mexican gray obsidian sources link a type of problematical deposit consisting of remnants of desecrated burials to household middens, indicating domestic origins for that type of special recovery context.

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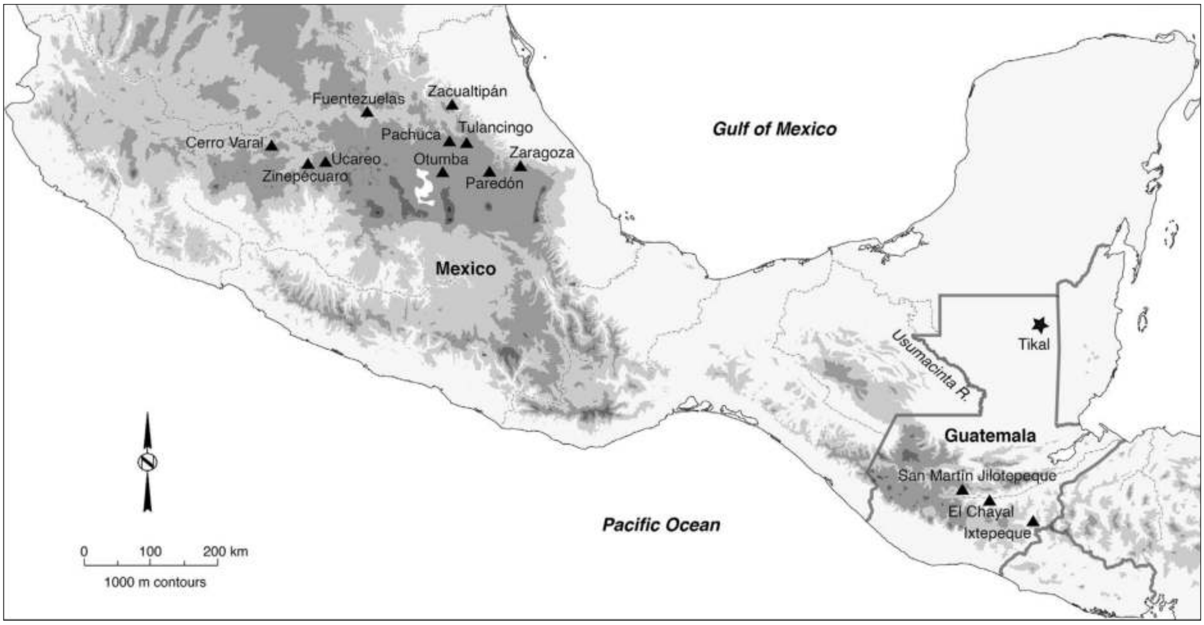

Figure 6.1. Map of Mesoamerica with the approximate locations of the geological sources of obsidian identified at Tikal. (Redrawn from Moholy-Nagy *et al.* 2013: Figure 1.)

Table 6.1. Tikal chronology.

Period	Long Count	Date	Ceramics
Early Postclassic			Caban
		AD 950	
Terminal Classic			Eznab
	10.2.0.0.0	AD 869	
Late Classic (late)			Imix
	9.13.0.0.0	AD 692	
Late Classic (early)			Ik
	9.6.0.0.0	AD 554	
Early Classic			Manik
	8.11.0.0.0	AD 250	
Terminal Preclassic			Cimi
		AD 150	
Late Preclassic (late)			Cauac
		AD 1	
Late Preclassic (early)			Chuen
		350 BC	
Middle Preclassic (late)			Tzec
		600 BC	
Middle Preclassic (early)			Eb
		800 BC	

The large numbers of Central Mexican sources represented in the sample suggest that those artifacts, for the most part thin bifaces (projectile points and knives), had first been aggregated at another location and then brought to Tikal.

Although the presence of El Chayal obsidian was overwhelming during the Late Preclassic and Classic periods, at no time in Tikal's occupation history was it the only source present.

El Chayal obsidian was brought in as large polyhedral cores (LPCs) for the production of prismatic blades by specialist knappers. A derivative industry was the fashioning of ceremonial lithics, i.e., obsidian eccentrics and incised obsidians. The earliest obsidian eccentrics were parsimoniously made on prismatic blade cores (Moholy-Nagy with Coe 2008: Figures 37 and 38). Some later examples (Moholy-Nagy with Coe 2008: Figure 36) and a uniquely Tikal type, incised obsidians (Moholy-Nagy with Coe 2008: Figures 51 and 54), used large flakes and blades struck directly from LPCs. The ventral faces of incised obsidians were engraved with symbols and deity representations. The use of imported material for ceremonial objects instead of utilitarian artifacts indicates greater imported quantities and possibly also greater elite involvement in the procurement of El Chayal cores.

Shaping the LPCs to the stage where prismatic blades could be produced from them created an impressive amount of debitage, which can be regarded as hazardous waste. Large buried debitage deposits, particularly from ceremonial contexts, give the

Table 6.2. Highland Guatemalan and Central Mexican sources identified in the analyzed sample.

Type	**Total**	**Guatemalan**	**Mexican and Unknown**	**Percent Guatemalan**	**Percent Mexican and Unknown**
Blade-Related	2330	2296	34	98.54%	1.46%
Maya Ceremonial	46	46		100.00%	
Thin Bifaces	32	5	27	15.63%	84.38%
Other	27	20	7	74.07%	25.93%

Recovery Context	Total	Guatemalan	Mexican and Unknown	Percent Guatemalan	Percent Mexican and Unknown
Burials	150	150		100.00%	
Caches	302	294	8	97.35%	2.65%
PDs	858	836	22	97.44%	2.56%
General Excavations/Unknown	1125	1082	43	96.18%	3.82%

Structure Group Type	Total	Guatemalan	Mexican and Unknown	Percent Guatemalan	Percent Mexican and Unknown
Civic-Ceremonial	1186	1165	21	98.23%	1.80%
Range Structure	289	276	13	98.23%	1.80%
Intermediate	269	263	6	97.77%	2.28%
Small Structure	449	427	22	95.10%	5.15%
Minor Center	210	209	1	99.52%	0.48%
Other/Unknown	32	27	5	84.38%	18.52%

Zone	Total	Guatemalan	Mexican and Unknown	Percent Guatemalan	Percent Mexican and Unknown
01-02 Epicentral	1344	1298	46	96.58%	3.42%
03-05 Central	563	543	20	96.45%	3.55%
00,06-26 Peripheral/Unknown	528	526	2	99.62%	0.38%

Date	Total	Guatemalan	Mexican and Unknown	Percent Guatemalan	Percent Mexican and Unknown
Postabandonment	2	2		100.00%	
Early Postclassic and earlier	14	14		100.00%	
Terminal Classic and earlier	284	278	6	97.89%	2.11%
Late Late Classic and earlier	355	353	2	99.44%	0.56%
Classic and earlier	321	302	19	94.08%	5.92%
Early Late Classic and earlier	363	349	14	96.14%	3.86%
Early Classic and earlier	779	753	26	96.66%	3.34%
Terminal Preclassic and earlier	183	183		100.00%	
Late Late Preclassic and earlier	30	30		100.00%	
Early Late Preclassic and earlier	74	74		100.00%	
Middle Preclassic	2	2		100.00%	
Pre-Columbian unspecified	28	27	1	96.43%	3.57%

impression that production went considerably beyond what was actually needed at Tikal. Furthermore, El Chayal predominates at other Classic period Lowland Maya sites. These two factors suggest Tikal had become both a production center and a significant marketplace for obsidian prismatic blades throughout the late Late Preclassic and Classic periods.

The Sample and Study Methods

Despite its large size, the analyzed sample has defects, the effects of which may bias our perceptions of obsidian import and use. The sample was selected by Lilita Bergs, who was researching prismatic blade technology. It tells us very little about other artifact types such as thin bifaces

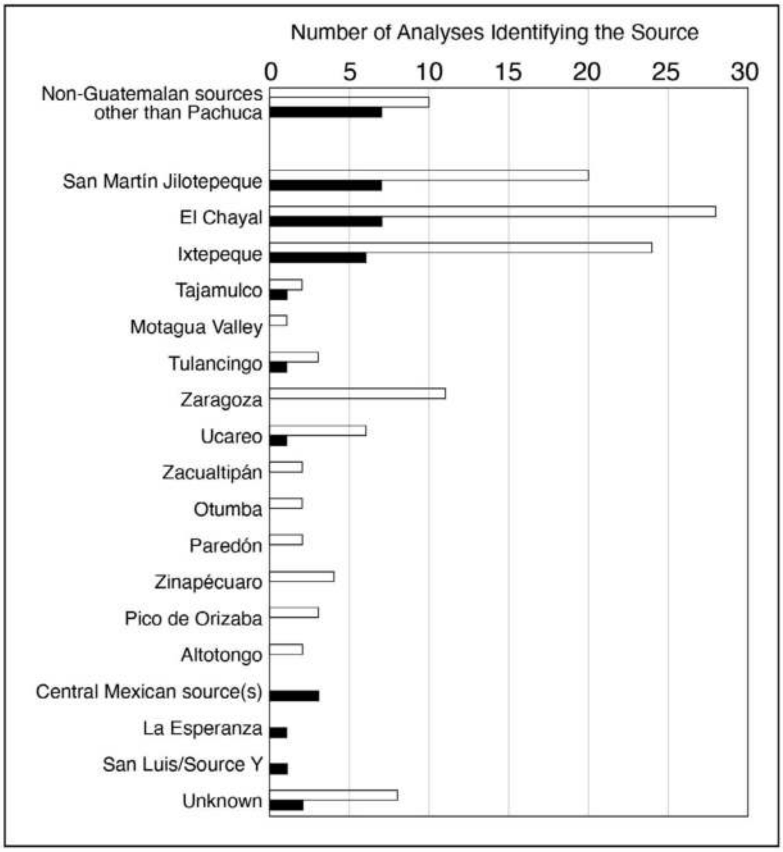

Figure 6.2. Comparison of the number of obsidian sources identified at the same Lowland Maya site by visual and instrument analysis. Black bars were visually attributed, white bars were attributed by instrument. (Redrawn from Moholy-Nagy 2003b: Figure 1, Tables 1–3).

and ceremonial lithic artifacts. Furthermore, I estimate the collection we attributed as perhaps one-third of Bergs' total selection. Therefore, while the results shown on Table 6.2, which are summarized from our earlier publication (Moholy-Nagy *et al.* 2013: Tables 2–7), further our understanding of the prismatic blade industry, it cannot be assumed that they are representative of site-wide obsidian procurement and use at Tikal without much more testing.

The Tikal Project has always had an interest in determining the geological sources of this imported material, which was common at Tikal and widely distributed throughout the Maya Lowlands. By the 1960s visual attribution of green obsidian artifacts to the Cerro de las Navajas source near Pachuca, Hidalgo, in Central Mexico seemed accurate, but visual sourcing is unreliable for the wide range in visual variability of gray obsidians, which actually range from almost colorless to black. The variations in color, opacity, luster, and inclusions within a particular source, such as El Chayal, are greater than visible differences between sources for the Guatemalan obsidians that constitute most of the obsidian recovered from Lowland Maya sites and also holds true for some gray obsidians from Central Mexican sources (Moholy-Nagy 2003b: Figure 1, 2; Moholy-Nagy *et al.* 2013: Supplemental Table 2). Another serious limitation to visual sourcing is that it can be used only on objects thin enough to transmit light.

At large sites like Tikal, where many sources may be present, visual attribution is worse than useless because even an experienced analyst cannot assign an unfamiliar sample to a source. According to present knowledge, an analyst could visually assign *all* of the obsidian in any collection of Lowland Maya Classic period artifacts to El Chayal with a respectable 90 percent accuracy rate, and yet miss all of the minor but culturally informative sources (Figure 6.2; Reid *et al.* this volume). In a comparison of visual and instrumental attributions of a sample of 30 obsidian artifacts from the site of Xkipche, Yucatan, one of the most energetic proponents of visual attribution gives two possible sources for 14 artifacts and three possible sources for two others (Braswell *et al.* 2011: Table 1). This kind of guessing is hardly useful. What makes pXRF attractive is the possibility of nondestructively sourcing rare artifacts and large sample relatively quickly, inexpensively, and objectively (Millhauser *et al.* 2011). Promising syntheses, such as social network analysis (SNA) (Golitko *et al.* 2012; Golitko and Feinman 2015), would be on firmer ground if they were based exclusively upon instrument attributions. Mixing in visual determinations unnecessarily muddies any conclusions.

There are known problems with using pXRF, particularly limits on minimum size and thickness. Sometimes these can be compensated for (Reid *et al.* this volume). Generally, the most effective way to source a collection of obsidian is to re-analyze unusual attributions by more exact methods, such as NAA or LA-ICP-MS (Laser Ablation Inductively Coupled Plasma Mass Spectrometry).

Attributed Geological Sources

The EAF analysis identified 11 geological obsidian sources among the analyzed sample. Three were from the Guatemalan Highlands and eight from Central Mexico. Two Mexican sources, Zinapécuaro and Paredón, had been identified earlier, bringing the total of geological sources present to 13. Additionally, a prismatic blade and two thin bifaces with differing chemical signatures could not be attributed to any presently known source (Moholy-Nagy *et al.* 2013: Table 2). Anecdotal observations at other Lowland Maya sites suggest that there is a positive correlation between the size of the site and the number of geological sources of obsidian identified by instrument (Moholy-Nagy 2003b).

The three Guatemalan sources, El Chayal, San Martín Jilotepeque (SMJ), and Ixtepeque, comprised somewhat over 97 percent of the analyzed sample (Table 6.2; Moholy-Nagy *et al.* 2013: Table 2–7, Supplemental Tables 4a-f). Of 2196 artifacts, 90 percent, came from the single source of El Chayal. Of the 101 artifacts attributed to Central Mexican sources, almost 40 percent came from two sources, Pachuca (n=24) and Otumba (n=16). Other gray Mexican sources were represented by only a few pieces.

Date

Prismatic blades were already present at Tikal's initial settlement in the Middle Early Preclassic period, the time of the Eb ceramic complex (Table 6.1; Moholy-Nagy 2003a: 34), but they were rare. Only one prismatic blade core could be dated to the succeeding Tzec ceramic complex. Flakes considered here as evidence of local blade production did not appear until the Early Late Preclassic period, the time of the Chuen ceramic complex. Eccentrics of obsidian, which co-occurred with eccentrics of local chert, made a sudden and plentiful appearance in elite cached offerings during the middle Early Classic period, the Manik 3A ceramic complex, but disappeared during the later Late Classic. Incised obsidians made on large flakes and blades taken directly from LPCs appeared at the beginning of the Early Late Classic period, the time of the Ik ceramic complex, and continued in use until the end of the Late Classic, the Imix ceramic complex. All ceremonial lithics of chert and obsidian disappeared with the cessation of elite activities by the Terminal Classic period, such as civic-ceremonial construction, stone monument erection, chamber burials, and the placement of standard offerings. Prismatic blades and thin bifaces continued in use until the final abandonment of the city.

The proportions of different sources changed over the course of the Preclassic and Classic periods. SMJ obsidian was prominent during the Middle Preclassic through Early Late Preclassic periods (Moholy-Nagy *et al.* 2013: Table 6). El Chayal was overwhelmingly dominant from the Late Preclassic, the time of the Cauac ceramic complex, until the end of permanent occupation of Tikal during the Early Postclassic period. Ixtepeque obsidian was present by the Terminal Preclassic or earlier and maintained a minor presence into the Early Postclassic period. Pachuca obsidian appeared to be most common during the middle to late Early Classic period, the time of the Manik 3A ceramic complex. This was also true of the Central Mexican gray obsidian sources. These changes over time are probably related to ethnopolitical developments (Meissner 2017).

The 2010 pXRF analysis confirmed this general impression and added some new information. Green obsidian, identified visually, does occur most frequently during the Early Classic period, but it appears as prismatic blades as early as the Early Late Preclassic, the time of the Chuen ceramic complex, and continues to occur into the Early Postclassic, the time of the Caban ceramic complex. This apparent contrast to the more limited occurrence of gray Mexican obsidian sources (Table 6.2) could imply a different mode of distribution, which could be investigated by further pXRF testing. On the other hand, it could reflect a bias toward more frequent recognition of green obsidian introduced by its distinctive color. It should also be kept in mind that obsidian from Pachuca can occur in gray and reddish varieties (Millhauser *et al.* 2011: Tables 6, 12).

Artifact Type and Source

We now have an enhanced understanding of the obsidian sources imported to Tikal and how the emphasis on these sources changed over time. However, it is the types of artifacts into which obsidian was worked that are essential to understanding why it was brought in over considerable distances for centuries. The Penn Museum's Tikal Project recorded well over 41,000 pieces of debitage, that is, the by-products of prismatic blade production, and 8269 prismatic blades, 878 obsidian eccentrics, 443 incised obsidians, 268 thin bifaces, 87 scrapers, c. 40 unclassifiable artifact fragments, and two small inlays and three incomplete earspools of ground and polished obsidian. No unworked obsidian was identified in the Tikal collections; it occurred either as artifacts or debitage. So much chert and obsidian debitage was encountered during excavations that an unknown portion was left in the field, and much that was brought in to the field laboratory was not counted or even weighed. The recovered debitage count for the Late Classic period is very incomplete.

The Tikal Project did not screen debitage deposits, so the recovered sample likely only includes production waste and little or no microdebitage from refurbishing or repurposing chipped stone artifacts. This is an unfortunate omission. Chert and obsidian debitage was invariably tidied up in the epicentral and central areas of the city, leaving no visible surface workshop deposits (Moholy-Nagy 1997). However, microdebitage embedded into the floors of activity areas might indicate a production locus and what was being produced (Clark 1986; Reid *et al*. this volume).

The behavioral sequence of prismatic blade production (Clark and Bryant 1997; Sheets 1975) demonstrates that by the Early Late Preclassic period, most of the obsidian intended for prismatic blade production was transported to Tikal in the form of LPCs. Size, form, and pXRF attributions suggest that perhaps only obsidian from the El Chayal source was imported as LPCs and that obsidian from other sources was mostly brought in as more extensively worked blade cores that left little production waste. The reduction of LPCs produced a great deal of debitage in the form of flakes, shatter, error recovery flakes, outer blades, and cores. Instrument analysis of early-stage LPC reduction debitage attributed all of it to El Chayal. It also reinforced the link between ceremonial obsidian artifacts and prismatic blade production suggested by the size and form of the artifacts and with the attribution of 42 obsidian eccentrics and two incised obsidians exclusively to El Chayal. These data suggest that the procurement of El Chayal obsidian as LPCs may have been organized and administered differently than cores from other sources.

During the Late Preclassic period, Tikal apparently became a gateway site for the importation of obsidian into the Southern Maya Lowlands. Throughout the subsequent Classic period, the quantities of obsidian debitage suggest that the city was producing prismatic blades and blade cores for exchange with other sites as well as for local use. Production at Tikal of prismatic blades with distribution via marketplace exchange is also suggested by the predominance of El Chayal obsidian in the obsidian assemblages of Late Preclassic and Classic period Lowland Maya sites (Golitko and Feinman 2015).

Some types of artifacts were made of certain geological sources, but apparently not of others (Table 6.2; Moholy-Nagy *et al.* 2013: Table 2). Selective use of sources might be related to the material characteristics of the obsidian, but potentially also to the place of origin of the artifacts (Meissner 2017), and to their function, use, and meaning. The absence to date of instrument attributions to El Chayal and SMJ of thin bifaces from anywhere in the Maya Lowlands is remarkable and should be investigated.

El Chayal n=2196

Prismatic blades and the small tools derived from them constitute over half of the attributed sample; nearly all of the rest is debitage related to prismatic blade production, including over 200 exhausted prismatic blade cores, many of them complete. A noteworthy aspect of transporting El Chayal obsidian to Tikal is how wasteful it was of material and the effort needed to bring it over a distance of more than 200 air-km. This is evident in large deposits of blade production debitage, much of it consisting of outer blades that we would deem usable (John E. Clark, personal communication 1982).

Three fragmentary ground and polished earspools (Moholy-Nagy with Coe 2008: Figure 131d, e) were also attributed to El Chayal. At present we can only speculate about where they were made.

San Martín Jilotepeque n=132

Nearly all of the artifacts attributed to SMJ were prismatic blades. However, 37 pieces of blade production debitage indicate that at least some SMJ obsidian was imported as cores.

Ixtepeque n=33

Approximately half of the examples attributed to Ixtepeque were prismatic blades. There were 16 fragments of blade production debitage. What is noteworthy, in the lack at present of other Guatemalan sources, is that five fragmentary thin bifaces were sourced to Ixtepeque. In the absence of testing, it is not known exactly when or how numerous thin bifaces of Ixtepeque obsidian actually were at Tikal. If more thin biface attributions could be made, it might become possible to distinguish thin bifaces of Ixtepeque obsidian from those imported from Central Mexico by type. It may also be significant that thin bifaces of Ixtepeque obsidian appear during the Late Classic period, after the initial occurrence of thin bifaces from Central Mexico.

Cerro de las Navajas, Pachuca, Hidalgo n=556 total of which only 24 were attributed by instrument

Almost 80 percent of the obsidian assumed to be from this Central Mexican source occurred as prismatic blades. Debitage is very rare, but at least 23 small fragments are present, which suggests that most Pachuca obsidian arrived at Tikal as cores that could be locally reduced without additional preparation. Thin bifaces (n=79) made up 14 percent of the total sample of recorded green obsidian and 29 percent of the total recorded sample of 268 obsidian thin bifaces. Nine of the ten obsidian eccentrics of Central Mexican style found at Tikal (Moholy-Nagy with Coe 2008: Figure 34) were of green obsidian. Green obsidian eccentrics are distinctive in form and technique. They have never been found in standard Tikal caches or burials.

Green obsidian is often uncritically regarded as a sign of contact with the Central Mexican city of Teotihuacan. However, it is present at Tikal in minor quantities from the Early Late Preclassic through Early Postclassic periods. The more restricted temporal occurrence of thin bifaces and eccentrics of Mexican type is more convincing evidence of contact with Central Mexico.

Three large, unmodified pieces of green obsidian struck from LPCs show signs of edge use (Moholy-Nagy 2003a: Figure 68m, ee). They are best regarded as finished expedient artifacts.

One of the rare broad prismatic blades identified at Tikal was of green obsidian; another was sourced to Zaragoza (Moholy-Nagy 2003a: Figure 70a, b). The broad blades are about 2.5 cm wide, twice as wide as most Tikal prismatic blades. Their use is unknown, but might be determined by use-wear analysis.

There are no contextual data that indicate Pachuca obsidian was valued for its green color. More likely it was valued for its excellent chipping quality. As noted above, obsidian from Pachuca occurs in colors other than green, so it is likely to be underrepresented in visually attributed collections.

At Tikal green obsidian thin bifaces and prismatic blades occur in the same recovery contexts as the same artifact types of gray obsidian, which demonstrates that they had the same functions, uses, and meaning (Moholy-Nagy 1999). This casts doubt on the notion that, at least at Tikal, green obsidian artifacts, with the possible exception of the rare eccentrics, were exchanged as gifts rather than commodities or were markers of elevated social status (Spence 1996). As a component of Tikal's market economy (Chase and Chase 2020: 139–140), they appear to have been available to anyone who could afford them and were acquired for their utilitarian function. However, Mexican obsidian, particularly from Pachuca, might well have been a prestige good at sites that were not as well connected and well provisioned as Tikal.

Other Central Mexican sources: Tulancingo/Pizzarín, Paredón, Otumba, Cerro Varal, Zaragoza, Fuentezuelas, Ucareo, Zacuáltipan, Zinapécuaro n=39

The green Tulancingo/Pizzarín source is included here with the gray sources because it also comes from Central Mexico and also has gray variants (Millhauser *et al.* 2011: Table 6). It is rare at Tikal. It is represented by only three small flakes, probably all from the same thin biface, which were a darker, less golden green than obsidian usually identified visually as from Pachuca.

Only 27 of the 268 thin bifaces of obsidian recorded by the Tikal Project have been attributed to source because of the reluctance to damage or destroy these relatively uncommon artifacts. The results of pXRF attribution can be described as tantalizing. To date, only five fragmentary thin bifaces have been attributed to a Guatemalan geological source, that of Ixtepeque (Moholy-Nagy 2003a: Figures 66b, 67w); the others are of gray and green Central Mexican sources. The impression of procurement as finished goods is reinforced by the circumstance that nearly all identifiable examples are of Central Mexican type (cf. Moholy-Nagy (2003a: Figures 64–68h; Tolstoy 1971: Figures 2, 3). The earliest thin bifaces of Mexican obsidian date to the middle of the Early Classic period and continue in use until the Terminal Classic, while the thin bifaces of Ixtepeque obsidian appear to be no earlier than the Late Classic. Testing by pXRF at Tikal and other Lowland Maya sites might indicate if thin bifaces of Ixtepeque obsidian met an increased demand for thin bifaces or compensated for difficulties in obtaining goods from Central Mexico. The initial appearance of Central Mexican thin bifaces during the time of maximum Teotihuacan stylistic influence during the Manik 3A ceramic complex adds another facet to the ongoing discussion of the nature of Teotihuacan-Tikal relations.

Three samples, an outer blade, a thin biface fragment, and an unclassified fragment were first attributed to the La Esperanza source in Honduras. But in the absence of any other identified material traces of Honduran origin at Tikal, these artifacts and others were submitted to the University of Missouri-Columbia's Research Reactor (MURR) for testing by NAA, where they were re-attributed to the Cerro Varal source in Michoacán (Moholy-Nagy *et al.* 2013: 77, Table 2). This was a helpful, if cautionary discovery that shows that unexpected and unique results not supported by other evidence should be carefully reviewed.

Altogether five prismatic blades, a broad blade, seven outer blades, and a small chunk could be attributed to Central Mexican gray obsidian sources. Even though all of the green obsidian is assumed to be of Central Mexican origin, its possibly more frequent presence, greater formal variety, and considerably longer duration of occurrence suggest a distribution system that differed from that of the gray Mexican sources. Moreover, most green obsidian may have moved as extensively worked prismatic blade cores intended for the local production of prismatic blades, while the scarcity of debitage suggests that most Mexican gray sources may have been brought in as finished artifacts.

Unknown Gray Sources n=3

One prismatic blade fragment and two thin biface fragments could not be attributed to known geological sources.

Exchange Networks

A consideration of the interrelationships of date, geological source, and artifact type suggests that several long distance, inter-regional exchange networks brought obsidian to Tikal during its occupation. Apparently several procurement systems may have been operating to bring in different sources and different types of artifacts. This notion is tentative and needs a good deal more pXRF testing of gray obsidian artifacts. If examined by artifact type, it is evident that prismatic blades were produced from obsidian from diverse geological sources, although the attributed blade production debitage is almost exclusively El Chayal. Ceremonial lithic artifacts of Maya style were of El Chayal. Rare eccentrics of Teotihuacan style were imported as finished artifacts. Identifiable thin bifaces appear to be stemmed dart points, but some fragments could also be from knives or other bifacial artifacts (Moholy-Nagy 2003a: Figure 68a-h). With the exception of only a few examples of Ixtepeque obsidian, thin bifaces were of Central Mexican green and gray obsidian.

A fascinating question that needs to be investigated is how, for example, a dart point made of obsidian from Cerro Varal in Michoacán ended up in the hands of a nonelite resident of Tikal in the Southern Maya Lowlands. SNA can construct intersite networks at regional scales. It can be used to define areas in Mesoamerica that interacted with each other in the procurement, production, and use of obsidian (Eppich 2020; Feinman *et al.* this volume; Golitko and Feinman 2015; Golitko *et al.* 2012; Meissner 2017). Furthermore, the impact of ethnopolitical organization on changing patterns of obsidian procurement can be assessed by focusing on the types of artifacts made of imported obsidian, such as small projectile points and debitage (Meissner 2017). The attribution by pXRF and SNA of thin bifaces and especially of debitage could help to delineate the real-world aspects of goods exchange.

Recovery Context

The recovery contexts of artifacts of different geological sources provide information on their past systemic function. Obsidian artifacts, especially prismatic blades, were common in general excavations in Tikal's epicentral and central areas. Most show obvious traces of edge use. They are generally assumed to have been of utilitarian function.

The function of the largest obsidian concentrations, in the form of blade production debitage, is more ambiguous. They were specially deposited exterior to chamber burials or within cached offerings (Moholy-Nagy 1997: Figure 2) and were usually associated with much larger quantities of chert debitage from the final stages of biface production (Hall 1989). Any hypothesis about the function of the obsidian deposits, therefore, needs to take into account the associated chert. The composition of these deposits differs from household middens. They are very homogenous and do not include household trash, which suggests direct transfer from a workshop to the offering or burial (Johnson and Johnson 2019). The recovery context and deposit content imply a ceremonial function. However, the hazard and inconvenience posed by large quantities of nonbiodegradable stone fragments in a large settlement also suggest site maintenance as the primary impetus for subsurface deposition with conversion to an offering as a kind of afterthought.

El Chayal obsidian, unsurprisingly, occurred in nearly all recovery contexts, and it was the only source identified in a sample of 135 attributed pieces of debitage from deposits around chamber burials. SMJ and Ixtepeque obsidians occurred infrequently alongside El Chayal in PDs, caches, and general excavations. Of 46 ceremonial lithic artifacts tested to date, all were of El Chayal obsidian.

Virtually all of the green obsidian found at Tikal is in the form of finished artifacts, mostly prismatic blades and thin bifaces. Almost 72 percent of all green obsidian artifacts occurred in general excavations, with another 21 percent recovered from cached offerings and PDs, which appear to be disturbed or secondary burials (Moholy-Nagy 2019, 2021). One stela and two temple caches produced a total of nine fragmentary green prismatic blades that had been deposited with large quantities of blades and debitage of gray obsidian. The caches were from epicentral Group 5D-2 and all were of middle to late Early Classic date, i.e., the Manik 3A and 3B ceramic complexes.

The thin bifaces and rare blades of gray Central Mexican sources in the attributed sample also came primarily from general excavations. However, three outer blades were included in a large amount of debitage of chert and gray obsidian in a temple cache of late Early Classic date in Group 5D-2. A few Central Mexican thin bifaces and prismatic blades were found in PDs.

The recovery contexts of finished green and gray Mexican obsidian prismatic blades and thin bifaces indicate that, at least at Tikal, they were not prestige goods. What imported material is made into and used for is just as significant as its place of origin.

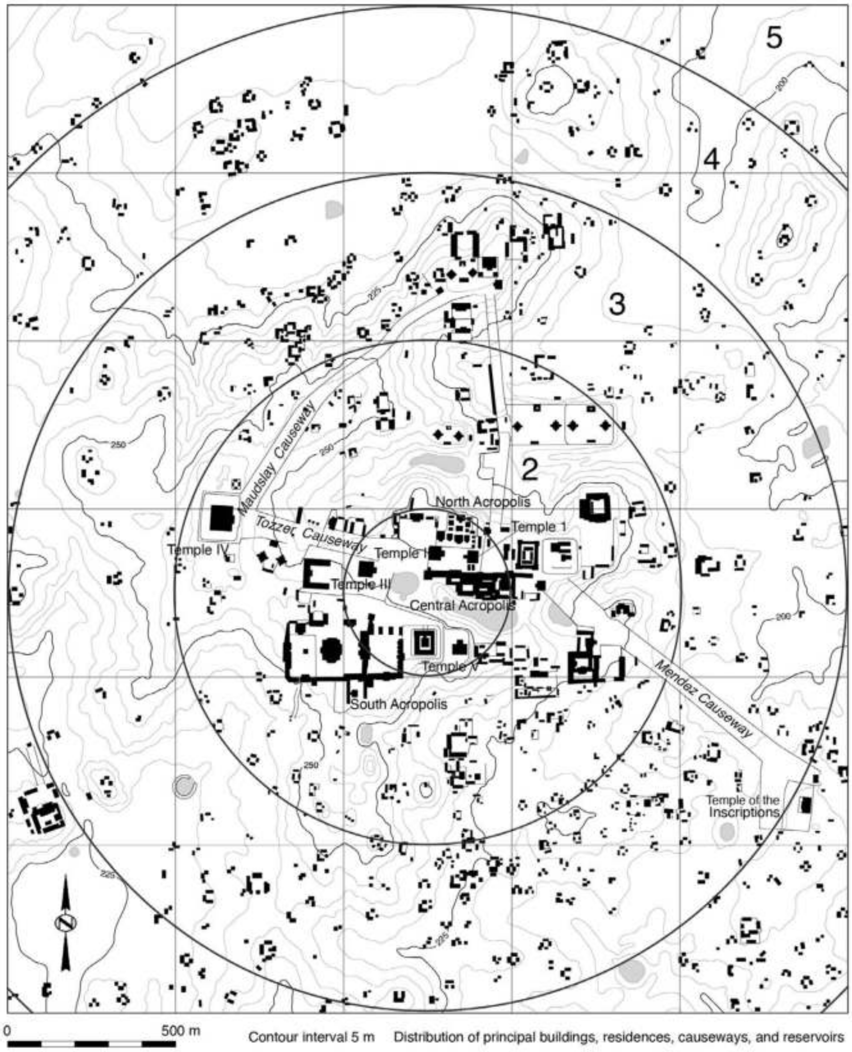

Figure 6.3. A set of concentric zones superimposed on a map of central Tikal extending to the boundaries of the Tikal National Park. Zones 02-26 each have a half-km radius, while Zone 01, which encompasses most of epicentral Group 5D-2, has a radius of 0.25 km. (Diagram by the author.)

Structure Group Type and Zones

Distribution of sources among different kinds of structure groups indicates which social groups used which sources and for which purposes. Structure group type is not particularly informative for obsidian utilization, inasmuch as the different Guatemalan and Mexican sources were represented in all types of structure groups, even in the perishable residences thought to have been the homes and workshops of commoners (Moholy-Nagy *et al.* 2013: Table 4).

However, by the end of the Classic period, Tikal had a roughly circular settlement plan, which Puleston (1983: Figure 21) divided into epicentral, central, and peripheral areas according to settlement density. Guatemalan sources, overwhelmingly El Chayal, were especially well-represented in the epicenter by blade-production debitage specially deposited around chamber burials and caches, and possibly by hundreds of as-yet unattributed ceremonial lithic artifacts.

A significant socioeconomic variable of obsidian consumption is the distance from Tikal's epicenter (Moholy-Nagy *et al.* 2013: Table 5). This variable can be visualized as zones, imaginary concentric rings of 0.5 km centered on square 5D of the site map (Figure 6.3; Carr and Hazard 1961; Moholy- Nagy *et al.* 2013: Table 5). Beyond Zone 05, i.e., beyond a radius of about 2.25 km from the center of Group 5D-2, the number of artifacts, artifact types, and sources declines noticeably, until only a few prismatic blades of El Chayal obsidian occur at the outermost peripheries. Some of this reduction may be due to sampling, inasmuch as more excavation was carried out in the epicentral and central areas (Moholy-Nagy 2003a: Chart 1.3). Still, the larger peripheral structure groups of Zones 09 and 20 did not include much obsidian. No obsidian from SMJ was identified beyond Zone 12 nor from Ixtepeque beyond Zone 14. This kind of spatial distribution, weighted towards the site center, was also true of most kinds of artifact types and materials (Moholy-Nagy 2003a; Moholy-Nagy with Coe 2008) and can be regarded as an indication that economic rather than social factors determined access to obsidian artifacts (Hirth 1998).

Conclusion

Despite the unsatisfactory nature of the sample, the EAF's analysis demonstrated the considerable potential of pXRF to produce useful replicable results and indicate future topics to investigate.

Statistical techniques like SNA (Golitko *et al.* 2012; Golitko and Feinman 2015; Meissner 2017) can trace the extent and intensity of interaction between polities. It can provide overviews at regional and finer scales. It could be applied to tracing out routes and identifying the actors and locales in the very long supply chain that brought several sources of Central Mexican obsidian to Tikal. There is still no consensus about which segments of Tikal society organized imports. There may well have been several procurement systems in operation at the same time, as well as at different times (Chase and Chase 2020; Eppich 2020; Hutson 2020).

At the scale of the individual site, large samples attributed by pXRF can make useful contributions when they are linked to cultural variables, such as artifact type, recovery context, and spatial distribution. The use of pXRF can now be applied to understudied artifacts such as thin bifaces, ceremonial lithics, and to entire deposits of production and refurbishing debitage. A study focused upon thin bifaces would be especially worthwhile. Most of the gray Central Mexican obsidian sources were identified in thin bifaces, specifically in stemmed dart points. Thin bifaces of obsidian appear during the later Early Classic period, a time of emulation of selected Teotihuacan cultural traits (Willey 1991), and may have been initially adopted for ideological, as well as practical reasons (Carballo 2007; Moholy-Nagy 2021). However, stemmed bifaces continued in use into the Late Classic period beyond the most intense period of Teotihuacan emulation and a yet-unknown proportion was made of Ixtepeque obsidian.

It would be highly informative to locate and examine as much as possible of the entire collection of obsidian artifacts recovered by the Penn Tikal Project. Although we worked sixty years ago, documentation of the collection is exemplary. Additionally, attributions of debitage and artifacts at other Lowland sites might provide data on supply chains. Attention to improving pXRF methods and increased sourcing of artifacts can provide objective, empirically based results to the study of obsidian procurement, use, and discard.

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Chapter 7

Classic Maya Obsidian Blades: Sourced from Afar and Produced in the Local Marketplace

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Abstract

Among the lowland Classic Maya, studies of household consumption patterns and marketplace facilities have demonstrated that obsidian blades were made available through marketplace exchange networks. The juxtaposition of obsidian as a non-local resource and local production of blades within marketplace facilities demonstrates greater complexity in the obsidian economy than previously recognized. I present a case study from the site of Buenavista del Cayo, located in the Mopan River Valley, Belize, to examine this complexity. Based on pXRF analysis, most obsidian stemmed from the Guatemalan source area of El Chayal, which was commonly exploited by other major sites in the valley at the time. This was beneficial to the vendor-producer who could spend less time acquiring raw materials. The communication and agreement to participate in trade from El Chayal among multiple polity leaders also was a cost saving measure, that is until conflict or competition to control trade networks arose.

Introduction

As a natural resource with limited source locations in Central America, obsidian has become a classic example from which to analyze long-distance exchange networks and differential consumption among the ancient Maya. For a long time, scholars of the Maya Lowlands focused on obsidian objects as those that conferred a higher status upon their owners. The distribution of such goods would likely have been under the control of an elite class and doled out based on social or political relationships (Sidrys 1976). Obsidian objects, in particular blades seemed to appear in houses of different economic or social status, however. Prudence Rice (1987) addressed this conundrum with a quantitative analysis of Late to Terminal Classic (AD 600–900) household obsidian blade consumption in the Peten, Guatemala, and suggested that for households of different status to obtain these goods, there was likely an accessible centralized method of exchange in place.

More recently, studies have shown the existence of Classic period (AD 250–900) Maya market exchange networks and marketplace facilities that support Rice's suggestion (e.g., Cap 2015a, 2015b, 2019; Chase and Chase 2014; Dahlin *et al.* 2010; Huston 2017; King 2015; Masson and Freidel 2012; Masson *et al.* 2020; Roche Recinos 2021). Indeed, as an imported raw material, obsidian played an early role in the identification of market exchange, specifically in studies that drew on the Kenneth Hirth's (1998) distributional approach, which focuses on similarity in household consumption across status groups (e.g., Chase and Chase 2014; Eppich 2015; Halperin *et al.* 2009; LeCount 2016; Masson and Freidel 2012). These findings indicate the development of extensive networks of communication and cooperation within and between political spheres, which has reshaped understandings of the organization of Classic Maya society.

To date, only a handful of Classic Maya marketplace venues have been identified (Cap 2015a, 2015b, 2019; Dahlin *et al.* 2010; King 2021; Roche-Recinos 2021; Wurtzburg 1991). At two of them I discovered obsidian blades were produced within the marketplace venue by vendor-producers (Cap 2015a, 2015b, 2019). Moving beyond just the identification of obsidian blades as a good that moved through market exchange networks, these finds allow for a discussion of obsidian exploitation and production for market exchange. While sourced from afar, the blades were made in the marketplace which suggests more complex and diverse actions and networks are involved in the obsidian economy than previously thought.

To examine this complexity, I present here the obsidian assemblage recovered from the Late to Terminal Classic (AD 600–900) marketplace at the site of Buenavista del Cayo, located in Mopan River valley, Belize. In the analysis of the assemblage, I take into consideration indicators of raw material conservation to discuss possible values (broadly defined) of obsidian, I also briefly discuss available household consumption data for similar purposes.

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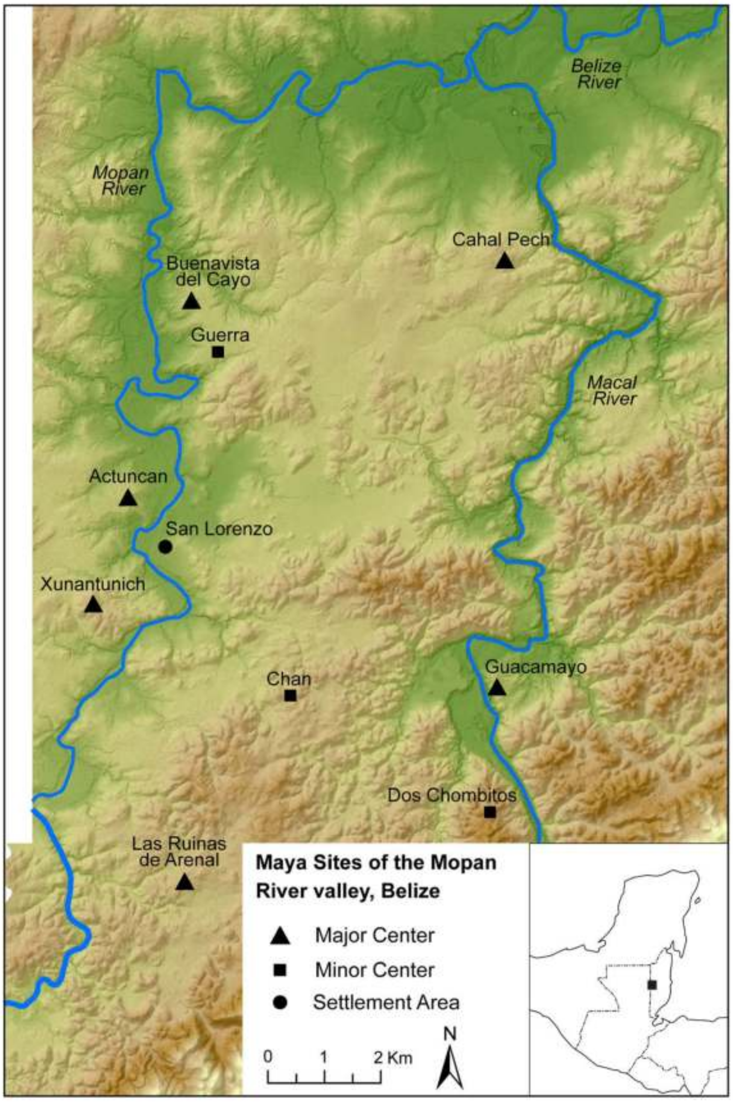


Figure 7.1. Location of Buenavista del Cayo within the Mopan River valley, Belize.

Buenavista del Cayo

Buenavista del Cayo is located just east of the Mopan River (Figure 7.1), a major transport corridor between the Caribbean coast and interior reaches of what is now Guatemala. The site was occupied from the Middle Preclassic to Terminal Classic periods (1000 BC – AD 900) (Ball and Taschek 2004, 2018; Peuramaki-Brown 2012), with its apogee starting in the Early Classic period (c. AD 400s). In the AD 600s it was competing for power with the site of Xunantunich, located 5 km downstream, and was eventually superseded by it sometime in the mid AD 700s to early AD 800s. Xunantunich is the location of another marketplace with evidence for obsidian blade production (Cap 2019; Keller 2006). Elsewhere, I have suggested that competition for control over trade routes of imported goods, such as obsidian, may have played a role in the political dynamics between the two sites (Cap 2021).

The architectural center of Buenavista del Cayo (hereafter referred to as Buenavista) consists of four plazas (what today appear to be open areas) (Figure 7.2). Adjacent to the West Plaza is the Palace complex where royal elites resided, held court, and in some cases were buried (Helmke *et al.* 2008). The North Plaza is delimited by household or administrative buildings as well as a sunken ballcourt. The Central Plaza was the Classic period religious center of the urban core and the site of several royal burials (Yaeger *et al.* 2015). The East Plaza, the focus of the study presented here, was the earliest religious precinct as noted by a Preclassic Cenote-style E Group (Yaeger *et al.* 2016). The T-shaped structure on the eastern edge of the plaza was paired with a platform now buried deeply under Structure 3, located along the western edge of the plaza. In the Late Classic to Terminal Classic periods, the northern portion of the plaza served as a marketplace (Figure

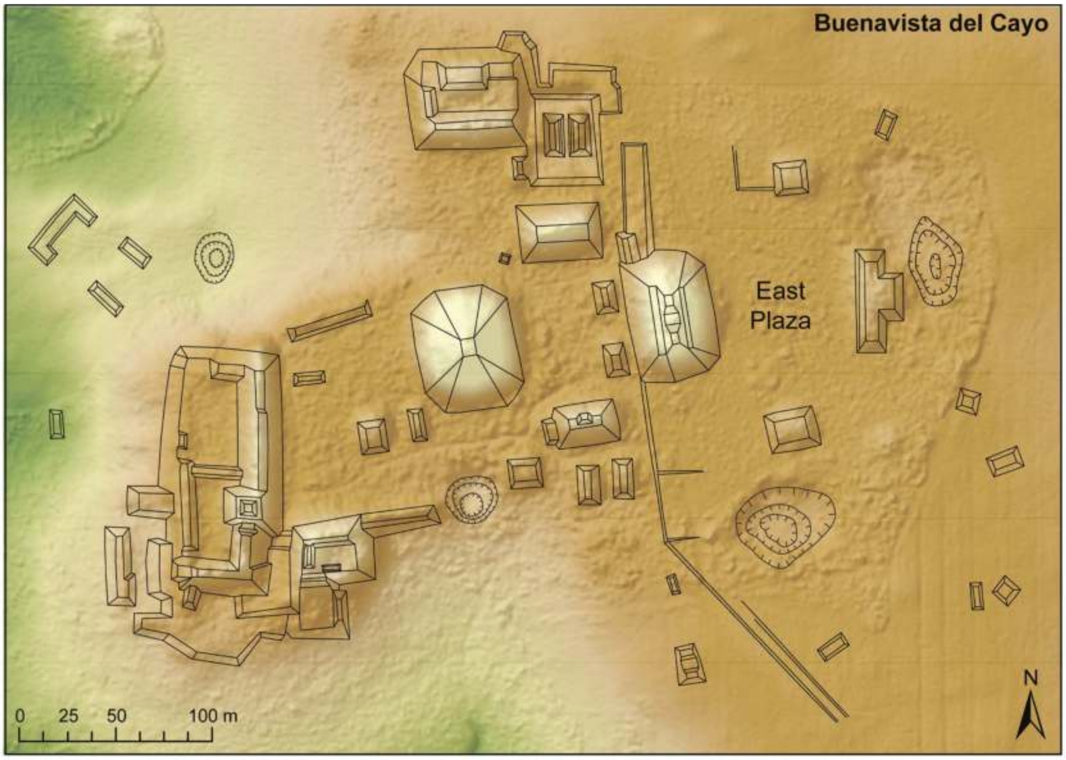


Figure 7.2. Map of the site center of Buenavista.

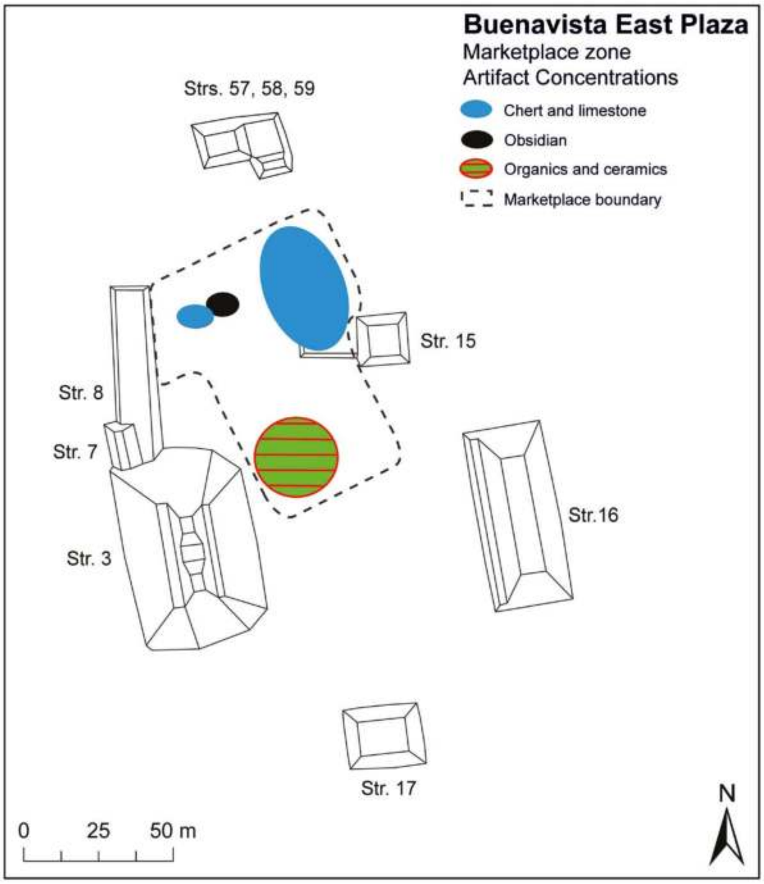


Figure 7.3. Location of the marketplace in the Buenavista East Plaza showing clusters of artifacts by material type.

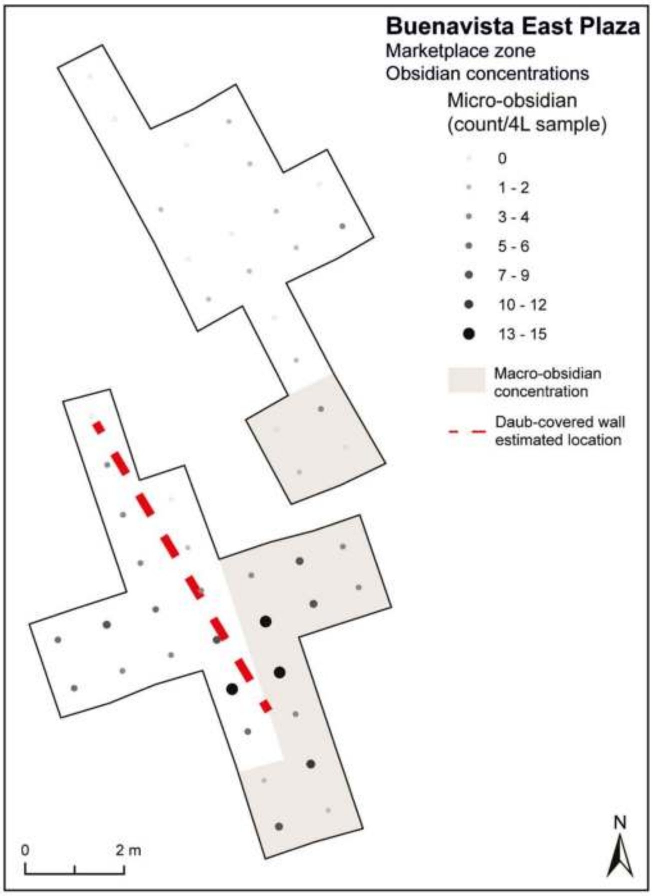


Figure 7.4. Excavation Area 1 within the Buenavista marketplace showing the distribution of obsidian debitage.

7.3). The chronological origins of the marketplace are not yet known.

Within the marketplace zone of the East Plaza, are statistically significant clusters of artifacts based on their raw material type (Cap 2015a, 2015b) (Figure 7.3). Two clusters consisted of chert and limestone debitage from the end-stage production of bifaces. Between these was a dense concentration of obsidian debitage. South of the lithic clusters was one cluster where high densities of both ceramics and organics (based on soil chemical analysis) overlapped. The types of goods represented here are those used in households for a wide variety of domestic activities, and similar to those found in market exchange studies based on household consumption patterns.

Each of the clusters is associated with built features, as indicated by stone architecture and distributions of micro-daub (4–2mm in diameter). The obsidian zone for example was delimited from the chert and limestone production zone by a wood-pole feature that was covered in clay. I interpret the architectural features as the remains of stalls that divided vendors. The building materials indicate the stalls were semi-permanent features making the marketplace a visible feature in the architectural center whether the marketplace was in session or not. The stalls also suggest a significant level of investment in the facility and support of market exchange activities (Cap 2021).

Resurfacings of one stall area revealed that it was in use from the Late to Terminal Classic periods, a time span of roughly 200 years. Multiple rulers would have reigned over this time frame which means that the success of the marketplace was not tied directly to a single ruler's authority or abilities. Rulers would have been important in the marketplace exchange networks however for their ability to maintain long-distance communication and peace across political borders as well as communication and transport over shorter distances.

Obsidian Blades in the Buenavista Marketplace

Production of obsidian blades in the Buenavista East Plaza is evidenced by a density of 40 macro-sized debitage/m3 of soil concentrated in a single area of the plaza designated as excavation Area 1 (Figure 7.4). Within Area 1 the presence of 174 micro-sized pieces

Table 7.1. Comparison of obsidian density at the Buenavista marketplace, workshops, and households in the Mopan River valley.

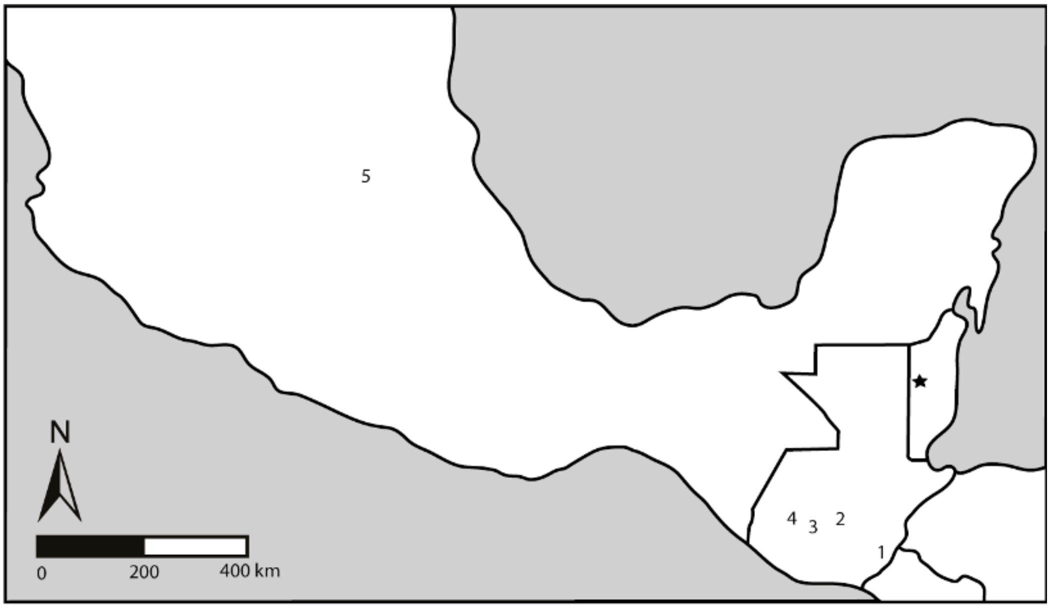
Site	Context/Activity	Total Count	Blade	%	Reduction Debris	%	Sources
Ojo de Aguas, Mexico	Chultun/Workshop	11,026	1,925	*17.5*	9,101	*82.5*	Clark and Byrant 1997
Laton Settlement, Upper Belize River valley	Household/Workshop	9,538	4,717	*49.5*	4,821	*50.5*	Hintzmann 2000; Olson 1994
Xochicalco, Mexico	Plaza/Marketplace	19,401	8,430	*43.5*	10,971	*56.5*	Hirth 2009
Xunantunich, Lost Plaza	Plaza/Marketplace	1,523	932	*60.8*	591	*39.2*	Cap 2019
Buenavista, East Plaza	Plaza/Marketplace	370	257	*69.5*	103	*27.8*	Cap 2015a
Buenavista, South Settlement Cluster	Household (n=5)/ Consumption	33	32	*97*	1	*3*	Peuramaki-Brown 2012
Chan Noohol	Household (n=6)/ Consumption	78	75	*96.1*	1	*1.3*	Robin 1999
San Lorenzo	Household (n=19)/ Consumption	645	642	*99.5*	3	*0.5*	Yaeger 2000

Table 7.2. Summary of pXRF results of Buenavista marketplace obsidian assemblage tested at the Field Museum's Elemental Analysis Facility.

Obsidian Source	Blade Count	%	Debitage Count	%
El Chayal	249	*91.8*	64	*90.1*
Ixtepeque	17	*6.3*	6	*8.5*
San Martin Jilotepeque	4	*1.5*	0	*0*
Unknown	1	*0.4*	1	*1.4*
Total	271	*100*	71	*100*

of obsidian (4–2 mm in diameter) is suggestive of in situ production. The density of obsidian debitage is low compared to workshop spaces found elsewhere (Table 7.1). Limits on space in a marketplace have a high potential to restrict the amount and type of production that can take place. Production in the marketplace is also more likely to involve fewer people working at a lower intensity or more sporadically then would take place in a workshop setting. Cleaning between marketplace sessions would also effectively remove evidence of production. The density of obsidian in households within the valley is much lower than in the Buenavista marketplace, however. No household-based obsidian workshops have been found within the Mopan River valley proper. This contrasts with several identified workshops focused on working chert, a locally abundant resource, within the valley (Hearth 2012; Vandenbosch 1999). A large, dense obsidian workshop is located near the site of El Pilar at the small settlement of El Laton (Hintzman 2000; Olson 1994), roughly 10 km north of Buenavista, which could have been a hub for obsidian vendor-producers.

Sourcing of 341 out of the 370 macro-sized obsidian fragments recovered in Area 1 excavations took place at the Field Museum's Elemental Analysis Facility by Mark Golitko, Jim Meierhoff, and Caleb Kestle (Table 7.2). One fragment was from an unknown source and all others were from Guatemalan sources, as is most common for the Mopan River valley (Meierhoff *et al.* 2012; Peuramaki-Brown 2012; Schults 2012; Tritt 1997). Dominating the assemblage is obsidian from the El Chayal zone (Figure 7.5). During the Late Classic period, it was the most exploited source throughout much of the southern Maya lowlands (Dreiss and Brown 1989; Hruby 2006; Kovacevich 2006; Meierhoff *et al.* 2012;



★ Approximate location of Buenavista del Cayo
Obsidian sources: (1) Ixtepeque; (2) El Chayal; (3) Media Cuesta and San Bartolome Milpas Altas;
(4) San Martin Jilotepeque; (5) Pachuca.

Figure 7.5. Location of obsidian sources in relation to the site of Buenavista.

Table 7.3. Types of debitage present in the Buenavista marketplace obsidian production zone.

Artifact Type	Macro Count	%	Micro Count	%
Finished Good				
Blade fragment	257	*69.5*	25	*14.3*
Production Debris				
Flake	42	*11.4*	56	*32.2*
Shatter	48	*13*	60	*34.5*
Core Rejuvenation	13	*3.5*	0	*0*
Unknown	9	*2.4*	33	*19*
Adornment	1	*0.2*	0	*0*
Total	**370**	***100***	**174**	***100***

Moholy-Nagy *et al.* 2013). Second in frequency was Ixtepeque obsidian, which at a regional scale was the source of choice during the Terminal period. It was exploited at lower frequencies in earlier periods, however (Ford *et al.* 1997; Nelson and Clark 1990). Finally, one blade fragment was from the San Martin Jilotepeque, a source utilized more commonly in the Preclassic (Meierhoff *et al.* 2012; Moholy-Nagy *et al.* 2013).

Within Area 1 the obsidian debris was recovered from a 10 to 20cm sediment layer that could not be stratigraphically divided. Thus, the sourcing patterns found could reflect several different indistinguishable situations. For example, Ixtepeque may occur at low frequencies because occupation and need for a marketplace dwindled during the Terminal Classic.

Obsidian debitage consisted of blades and core rejuvenation fragments (Table 7.3). All three obsidian sources are represented within the blade assemblage, but only El Chayal and Ixtepeque were found within the rejuvenation debris. The lack of San Martin Jilotepeque production debris could be a factor of a small sample size or possibly due to a different path of trade from this source.

An assemblage made up of nearly 30 percent rejuvenation debris provides clear indications that cores were brought to the marketplace and blades produced

Table 7.4. Count and density of obsidian blades present in the Buenavista Southern Settlement zone houses (after Peuramaki-Brown 2012: Table 7.4).

House Name	Site Type	Excavated Volume (m^3)	Obsidian Count	Obsidian Density/ m^3 of Sediment
BVS-003	1	1.5	1	0.7
BVS-004	1	13	23	1.8
BVS-005	3	1.2	8	6.7
BVS-006	3	16.7	63	3.7
BVS-033	1	0.6	0	0
BVS-035	1	1.2	0	0
BVS-036	1	1.5	1	0.7
BVS-037	1	6.5	2	0.3
BVS-060	3	9.9	28	2.8
BVS-077	1	5.7	6	1
BVS-086	1	1.6	2	1.3
BVS-087	1	1	2	1.3
BVS-099	1	0.7	0	0
BVS-100	1	0.9	0	0

on-site. (This contrasts with older suggestions that blades were pre-made and transported to exchange sites.) All blades lacked cortex. Of those blades I was able to assign to a production series (n=85), nearly all (n=75) were third series blades, which are those produced after a core has been shaped into a prismatic form (Clark and Bryant 1997). The pre-formed cores were likely small by the time they reached the marketplace given the small range of blade widths (0.3 to 1.7cm) and average width of blades (0.9cm). Blade width also aligns with expectations for sites near the end of trade routes (Rovner 1975:112–114) and conservation of the raw material.

All blades were broken, and no blade segment was more than 3.3cm long. The average blade length was 1.2cm. The average cutting edge to mass ratio (CE/m) of the assemblage is 21.6, which shows a high conservation of raw material.

Medial sections were the most abundant portion of the blade present, which reflects the act of segmenting blades into smaller pieces for use. I suggest the medial sections are possibly the most favored portion of the blade by consumers since they are most likely to have an even thickness compared to the proximal or distal ends. The medial sections recovered in the obsidian production zone have an average length of 1.1cm which may represent the least desirable by consumers. In fact, they may have been production rejects or waste.

A possible method to understand the production output of obsidian blades could be to create a minimum number of blades produced based on either proximal or distal count. It would be an interesting exercise, but because of the potential that marketplace was cleaned multiple times over its 200 plus years of use, I refrain from attempting this approach here.

Obsidian Blades in Buenavista Households

Household studies at Buenavista have concentrated on houses nearest the site center (Peuramaki-Brown 2012; Tritt 1997; Sandoval 2008) and a small village 1km south of the site center named Guerra (Taschek and Ball 1986; Tritt 1997). While there is not a representative sample to complete a robust distributional study of household obsidian consumption, the studies provide a starting point to begin comparisons.

Meaghan Peuramaki-Brown (2012) investigated the settlement cluster immediately south of the Buenavista site center (Buenavista South Settlement [BVS]) and recovered obsidian blades from 14 house sites (Table 7.4). She divided the houses into two types – Type 1 and Type 3 – based on criteria established by the Xunantunich Settlement Survey (Ashmore *et al.* 1994; Peuramaki-Brown 2012: Table 4.3, 4.4). Type 1 represents an isolated mound that has an elevation no higher than 2m. These are the smallest of houses and could represent the economically poorest or small family groups. Type 3 houses include anywhere from two to four mounds with at least two organized orthogonally and all have elevations that are no higher than 2m. These likely represent wealthier or larger-sized families.

Obsidian blades were absent from only four houses (all Type 1 sites) in the sample set. While 71 percent of households did consume obsidian blades, the number owned by each house is low. The count of blades recovered from house contexts throughout the Mopan River valley tend to be low (typically less than 50), however (e.g., Shults 2012:149–150; Robin 1999: Table 14; Yaeger 2000: Table III.17). House BVS-005, a Type 3 site, yielded the highest density of obsidian blades of all BVS house sites at 6 blades/m3 of sediment, which suggests some degree of variation between houses. Some of the differences in count could be due to archaeological sampling, while cultural factors could include the cost of obsidian blades or their function (and therefore household activities).

To source obsidian blades, Peuramaki-Brown (2012: Table 7.9) tested 38 fragments from four BVS houses using EDXRF at the McMaster Archaeological XRF Laboratory. Added to this is information are samples tested by Chad Tritt (1997: Table 9, 10) from the village of Guerra, who's occupants were likely participants in the Buenavista marketplace. Tritt (1997) used the EDXRF method to test a total of 76 samples, 29 of which were sent out in the 1980s to the Pennsylvania State University for analysis. The rest were tested at the Phoebe Hearst EDXRF Laboratory at the University of California Berkely in the 1990s (Tritt 1997:88). In both studies, the El Chayal source dominated in all contexts followed by Ixtepeque (Table 7.5), thus matching the pattern of sources found in the Buenavista marketplace. Other sources not found in the marketplace appear in the households, however, which could indicate different exchange methods or relationships.

Table 7.5. Summary of EDXRF results from household studies at Buenavista and Guerra (after Peuramaki-Brown 2012: 7.4; Tritt 1997: Table 9, 10)

	Southern Settlement Group	Guerra
Guatemalan Sources		
El Chayal	35	27
Ixtepeque	9	2
San Martin Jilotopeque	2	0
San Bartolome Milpas Altas	2	0
Mexican Sources		
Pachuca	4	1
Unassigned	6	1
Total Count	58	31

Discussion

The example presented by the Buenavista marketplace offers an opportunity to dig further into how market exchange was organized among the Classic period Maya. The story made apparent at Buenavista is that preformed obsidian cores were brought to the marketplace where they were then worked into individual blades by a vendor-producer. Production within the marketplace facility itself was to the advantage of the vendor-producer who could make only the number of blades needed, thus conserving raw material that required extensive time and effort to bring to the Mopan River valley. The blades also would have fresh edges making for maximum cutting potential and happy customers.

Once the whole blades were made, the producer snapped them into segments and offered them for exchange to consumers who then took them to their houses for use. The short length of the blade segments and the mix of proximal, medial, and distal portions suggests that the debitage in the marketplace are rejects or trash from the production process. Even though conservation of the raw material was important, there was some discernment as to what type of blade was deemed suitable for household use.

Householders from different status groups (represented here by Type 1 and Type 3 style house sites) acquired the blades, but seemingly not in large numbers. It appears that the blades were a necessary tool in most houses but may have had special purposes. Obsidian is a brittle material which makes the use of blades suitable for a limited number of tasks. There are no other tools that produce as sharp an edge as obsidian blades in the Mopan River valley.

The dominance of El Chayal obsidian in the Buenavista marketplace follows the pattern observed at other sites in the Mopan River valley during the Late Classic period (e.g., Gotliko *et al.* 2012; Meierhoff *et al.* 2012; Schults 2012). An obsidian blade vendor-producer potentially saves time and effort by focusing on gathering materials from one source or interacting with fewer middlemen who provide the raw material. Participation in this regional exploitation pattern suggests agreement and communication across a wide region and among many different political leaders. By everyone tapping into the same source, each polity benefits and saves on costs and energy, much in the way that in the modern global market, buying in bulk can save a shopper. Alternatively, in times of conflict, manipulation or control over a dominant trade route could have been a way for rulers to gain power, a situation which may have been at play in the transfer of power between Buenavista and Xunantunich (Cap 2021; cf. Golden *et al.* 2008).

Who the vendor-producer was remains an unknown, but perhaps the Buenavista marketplace offers some clues about their identity. In the marketplace, obsidian blade production was separated from chert and limestone biface production. This same pattern is seen in obsidian (Hintzman 2000; Olson 1994) and chert (Vandenbosch 1999) workshops in the region. Thus, it appears that knappers specialized in their craft based on different raw materials or types of tools produced. Since the marketplace at Buenavista and the one at Xunantunich (Cap 2019) are the only currently known locations of obsidian blade production in the river valley, the knapper may not have been a full-time resident of the region. One possible location from which they might have travelled is the El Laton obsidian workshop (Hintzman 2000; Olson 1994). Of course, it is possible that with more time and research in the valley, a household-based obsidian workshop may be found and provide a different story of who the vendor-producers might have been.

Production of obsidian blades in the marketplace suggests more complex social and political networks were involved in the obsidian economy than previously recognized. For example, in modern markets, buying foreign/non-local goods can confer status on an individual, especially if locally produced goods are viewed as inferior (e.g., Banyopadhyay and Banerjee 2003; Kashi 2013; Nagashima 1970; Schooler 1965). Thus, even though consumption of obsidian blades is ubiquitous across household types/status, ownership of blades might still signify household wealth. Factors such as the number of blades owned or quality of the blades (e.g., length, width, thickness, straightness) might be more telling markers of status differences. Creating and maintaining the external relationships that bring obsidian into the Buenavista marketplace would have been important for rulers to demonstrate the broad reach of their power and commitment to the site's occupants. Purchasing locally made goods could be a signal of support to the local economy (e.g., McGrath *et al.* 1993; Tiemann 2008). Politically, this might indicate attempts to strengthen local connections and a ruler's authority.

The study presented here offers just one perspective of Classic Maya marketplace exchange networks that involve obsidian. It is a basis for comparison with other marketplaces and types of marketplace goods and has implications for understanding the complexity of Maya market exchange at the broad and small scales of society.

Acknowledgements

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Chapter 8

Macroscale Shifts in Obsidian Procurement Networks Across Prehispanic Mesoamerica

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Abstract

Obsidian was a vital Mesoamerican trade good throughout the prehispanic sequence. Here, drawing on an archive of more than 500,000 pieces of sourced obsidian with prehispanic contexts, we map and describe marked shifts in Mesoamerican exchange networks over 3000 years. Variation in the spatial and temporal patterns of obsidian procurement illustrate the diachronic dynamism of these networks, key transitions in the east-to-west movement of goods across time, and changes in modes of transfer.

Introduction

Scholarly lenses on premodern urban worlds have traditionally viewed them as spatially bounded, largely undynamic, and almost exclusively reliant on local resources (e.g., Finley 1999; Johnson and Earle 1987: 11–12; Lucas 2004; Polanyi *et al.* 1957; Sanderson 1991: 187; Webster 1994: 419). This perspective has been envisioned as especially apt for the ancient states of prehispanic Mesoamerica, where beasts of burden and wheels were absent, water-borne cargo transport limited, metal tools rare, and the terrain rugged (e.g., Sanders and Santley 1983; Webster 1985; Wright 1989: 99). Here, we probe these entrenched predispositions toward economic localism, self-sufficiency, closure, and stasis through the lens of a key commodity, volcanic glass, or obsidian, which was highly valued in prehispanic Mesoamerica. Obsidian can be modified to yield a sharp, durable cutting surface for which there were few material equivalents. The other principal advantage of obsidian for assessing these research issues is that it can be identified through compositional makeup to its volcanic source (e.g., Braswell 2003; Cobean *et al.* 1991; Glascock 2002). So, if we, as archaeologists, know where obsidian was recovered and can ascertain through analysis where that piece was mined, we can document the start and end points of that object's movement.

Mesoamerican obsidian sources have a constricted distribution in two broad volcanic bands, the Central-to-West Mexican Highlands, to the north, and the Guatemalan Highlands, to the southeast (Figure 8.1). Yet obsidian implements are almost ubiquitous at sites across the region throughout the prehispanic sequence, a pattern that is not in line with localism and is more indicative that Mesoamerican households were not self-sufficient and consumed goods they did not produce (Feinman 2013: 455). Drawing on a cumulated record of sourced obsidian from ancient Mesoamerican sites, we examine patterns of acquisition and distribution. Were local sources procured consistently by communities or was the transport of obsidian broad ranging? How did these patterns vary temporally and spatially? What can be inferred about the modes of transfer that were used to move obsidian artifacts to places far from their sources? We can see that the volume of obsidian and the distances that these materials traveled was often magnified and consistently shifted over time.

To investigate these questions, we began over a decade ago to systematically compile a comprehensive compendium of published obsidian data from archaeological contexts across Mesoamerica (Feinman *et al.* 2019; Golitko and Feinman 2015; Golitko *et al.* 2012, 2019). The impetus for this project was the purchase of a portable XRF spectrometer by the Elemental Analysis Facility (EAF) at the Field Museum and our subsequent sourcing of a collection of obsidian from the archaeological site of San José, Belize (Thompson 1939),

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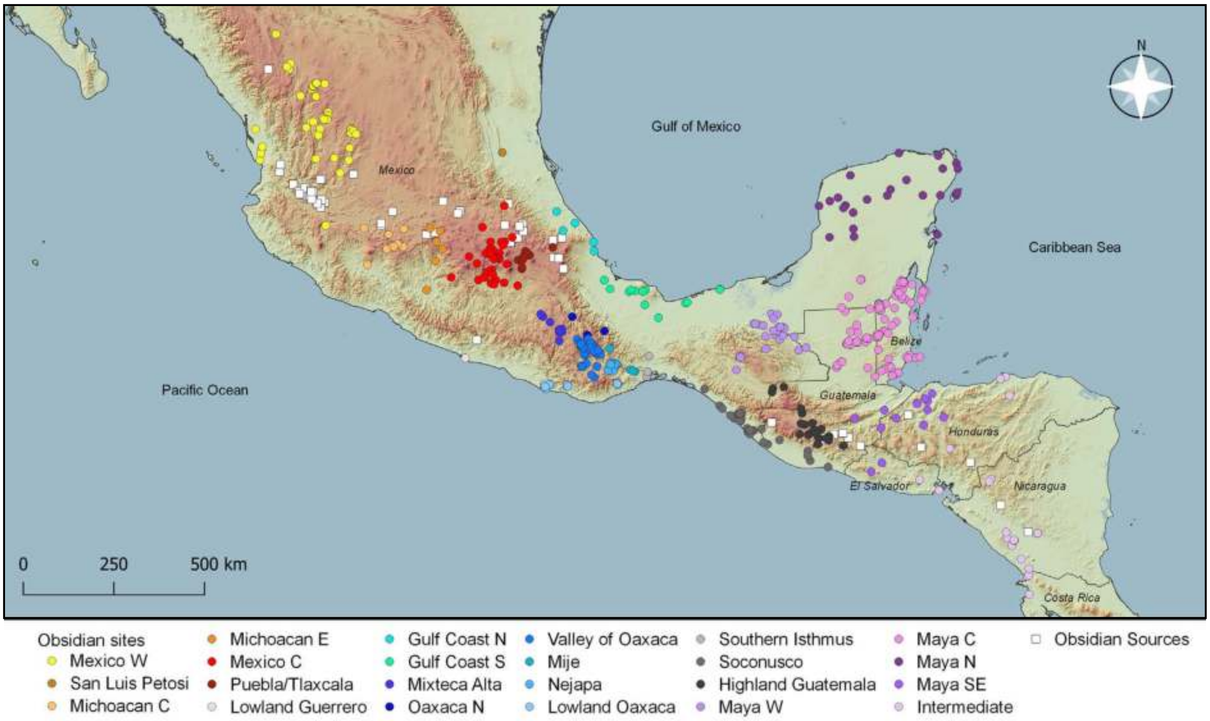

Figure 8.1. Location of obsidian sources in Mesoamerica and sites with sourced obsidian included in the database.

that is housed at the museum. This Classic Maya site—located between two important nodes on transport routes for obsidian at contact (e.g., Hammond 1972)—was excavated in the early 1930s by Field Museum curator J. Eric S. Thompson. To contextualize our findings on the San José obsidian, we archived published information on Classic/Postclassic sourced obsidian from the Maya region. Analyzing these data, we then found that changes in trade relations, a shift from inland to coastal trade routes, preceded the collapse of inland Maya urban centers (Golitko *et al.* 2012).

Once we compiled this information for the Maya, we noted that there was a lacuna of sourced obsidian from Oaxaca, in southern Mexico, where fewer than 500 pieces of obsidian had been sourced for all time periods (e.g., Pires-Ferreira 1976). There are no obsidian sources in the state of Oaxaca, so all archaeological obsidian arrived through long-distance exchange, making this region an ideal arena for addressing questions about exchange networks and how they changed over time. With this new technology in hand, we set out to facilities in Oaxaca where collections from archaeological excavations are stored. We began in 2012 with obsidian from the four sites we excavated for more than two decades and then worked with Mexican and North American colleagues to source obsidian from their excavations in the valley and elsewhere in Oaxaca. We did not sample but sourced all pieces above a certain size, generally ~1cm in length or width. Our initial analyses revealed dynamic shifts in obsidian distributions across Oaxaca over time and even synchronic variation in obsidian assemblages from individual sites (Feinman *et al.* 2013, 2018).

Through our own studies under the auspices of the Field Museum's Elemental Analysis Facility and the compilation of published information from other researchers, we have cumulated an archive that consists of more than 500,000 pieces of sourced obsidian from more than 450 sites across Mesoamerica. The sites in this archive are, for the most part, limited to the geographic area in which obsidians from either the Guatemalan-Honduran Highlands or Central Mexican Volcanic Belt (or both) predominated (Table 8.1). The lion's share of the information compiled in this archive was collected through broadly employed geochemical means (XRF, INAA, ICP-MS), although we do include visually sourced obsidian published by other scholars (e.g., Braswell *et al.* 2000).

In organizing the archive, we adhere to the chronological assessments of the original excavators/authors. Once compiled, sourced obsidian is assigned to one of ten 250–400-year time blocks that span the era from widespread sedentary settlement in Mesoamerica (~1600/1500 BC) through the time immediately prior to Spanish Conquest (AD 1520) (Table 8.2). This is an expansion of the seven time blocks we used in prior analyses (Feinman *et al.* 2019). We have enough data points now to break up what had been two 600-year blocks from 900 BC to AD 300 and to add another

Table 8.1. Mesoamerican sources present at sites in the obsidian archive

Macroregion	Code	Obsidian source	Zone
East	CG	El Chayal	Guatemala
East	IG	Ixtepeque	Guatemala
East	SMJ	San Martín Jilotepeque	Guatemala
East	GG	Tajumulco	Guatemala
East	BG	San Bartolomé Milpas Altas	Guatemala
East	MG	Media Cuesta	Guatemala
East	JG	Jalapa	Guatemala
East	GH	Güinope	Honduras/Nicaragua
East	EH	La Esperanza	Honduras/Nicaragua
East	SL	San Luis	Honduras/Nicaragua
East	NC2	Nicaragua-2	Honduras/Nicaragua
West	AV	Altotonga	Puebla/Gulf Coast
West	ZP	Zaragoza	Puebla/Gulf Coast
West	GP	Guadalupe Victoria	Puebla/Gulf Coast
West	PV	Pico de Orizaba	Puebla/Gulf Coast
West	MH	Malpaís	Central Mexico
West	PP	Paredón	Central Mexico
West	SH	Sierra de Pachuca	Central Mexico
West	SE	Santa Elena	Central Mexico
West	TH	Tulancingo	Central Mexico
West	PH	Tepalzingo	Central Mexico
West	ZH	Zacualtipan	Central Mexico
West	OM	Otumba	Central Mexico
West	PM	Pacheco	Central Mexico
West	UM	Ucareo	Michoacán
West	ZM	Zinapécuaro	Michoacán
West	CVM	Cerro Varal	Michoacán
West	ZNM	Zinaparo	Michoacán
West	CZM	Cerro Negra	Michoacán
West	PG	Penjamo	Michoacán
West	PQ	El Paraíso	Other West Mexico
West	FQ	Fuentezuelas	Other West Mexico
West	IRN	Ixtlán del Río	Other West Mexico
West	VNN	Volcán las Navajas	Other West Mexico
West	TQL	Tequila	Other West Mexico
West	HXL	Huaxtla	Other West Mexico
West	CMJ	Magdalena	Other West Mexico
West	JJ	La Joya	Other West Mexico
West	STJ	Santa Teresa	Other West Mexico
West	LLJ	La Lobera	Other West Mexico
West	HZZ	Huitzila	Other West Mexico
West	NCZ	Nochistlán	Other West Mexico
West	EG	El Ocotito	Other West Mexico

Table 8.2. Time blocks included in the Mesoamerican obsidian archive

Period	Designation	Dates
P1	Early Formative	~1600–1200 BC
P2	Early Formative	1200–900 BC
P3a	Middle Formative	900–600 BC
P3b	Middle Formative	600–300 BC
P4a	Late Formative	300 BC–AD 1
P4b	Terminal Formative	AD 1–300
P5	Early Classic	AD 300–600
P6	Late Classic	AD 600–900
P7	Early Postclassic	AD 900–1200
P8	Late Postclassic	AD 1200–1520

time block from ~1600/1500–1200 BC. Although some published sourced obsidian from Mesoamerica dates earlier than ~1600/1500 BC, we do not yet have enough data points from that time to create network graphs. Because nomenclature and lengths of chronological periods vary across the different regions of prehispanic Mesoamerica, we stick to broad period designations that correspond to those used in our prior publications (e.g., Feinman *et al.* 2019). Overall, this paper draws on the 429 sites in the obsidian archive that have sufficient chronological information to be placed in at least one of these 10 periods.

As we rely on obsidian that has been sourced and made available through publication, the period-by-period coverage is somewhat uneven, both spatially and temporally (Table 8.3). Yet the sample is sufficiently large to reveal robust patterns in the distribution of obsidian and how those patterns changed over time. Even though we have added many sites to the archive since our last publications (Feinman *et al.* 2019; Golitko and Feinman 2015; Golitko *et al.* 2012), the results and patterns are reasonably consistent with what we saw previously. Nevertheless, the results reported here do update, expand, and strengthen earlier findings and the inferences we drew from them. Despite the robustness of the archive for examining spatial and temporal patterns in obsidian procurement, it is not geared to examine precisely the volumes of obsidian that were procured through particular links over time and space.

A series of social network analytical methods (see Brughmans 2013; Knappett 2011 for recent syntheses) are employed to examine empirical shifts in obsidian source distributions and procurement over this ~3000-year span. Shared material culture, in this case the proportion of obsidian from each source at a specific site for a given period, is used as a proxy measure for

Table 8.3. Summary statistics by time period (* does not include sites with <5 pieces, which are excluded from network analysis)

Statistics	P1	P2	P3a	P3b	P4a	P4b	P5	P6	P7	P8
Total number of sites	24	34	28	26	24	32	90	179	87	129
Total obsidian	39364	19740	16007	8719	2334	3918	362149	52448	21088	35031
Mean sample size	1640	581	572	335	97	122	4024	278	242	272
Median sample size	81	49	73	40	31	30	25	34	21	37
Total sources	19	16	19	16	13	21	27	28	25	30
W. Mesoamerican sites*	13	19	13	12	12	17	25	39	45	55
Average number of sources per site	4.9	3.9	5.2	6.2	5.2	5.3	5.1	4.9	3.9	4
Highest number at any one site	11	10	11	11	11	13	15	12	9	9
E. Mesoamerican sites*	10	13	13	11	9	10	45	95	20	50
Average number of sources per site	2.8	2.4	2.9	2.2	2.4	3	3	3.8	3.9	3.6
Highest number at any one site	3	3	5	3	3	5	7	10	10	8

the degree or strength of the connectedness between specific settlements. As in our prior works, we calculate the Brainard-Robinson (BR) index of similarity (scaled from 0–1) to produce one-mode similarity networks linking sites to each other for each time block. Sites with fewer than five sourced pieces are excluded. We also correct BR indices for the effect of unassigned obsidian pieces by subtracting off a value corresponding to the increase in BR value that would occur were these unassigned pieces from one site to come from sources that were also present at the comparison site. For visual clarity, we eliminate low-strength ties between sites using the so-called 'mini-max' approach, i.e., removing links up to the strength at which the network begins to fragment (Golitko and Feinman 2015—in some cases one or two sites that are only weakly connected to the rest of the network become isolates). Link (or edge) thickness represents tie strength. We position nodes (sites) in two ways: 1) using the Fruchterman-Reingold force-directed algorithm to position nodes by their approximate network proximity (Fruchterman and Reingold 1991) and 2) using geographical coordinates to show the distribution of links in terms of real-world geography (Figure 8.2).

Additionally, for each time block, we generate two-mode networks in which sites are linked to each other through the obsidian sources present at each site, with edge thickness representative of the relative percentages present at each site. Nodes are colored by 'zone,' providing an indication of their relative geographical location within the study region. This categorization is purely for visualization and has no analytical significance. Networks were generated in the *R* statistical environment using the *igraph*, *network*, and *sna* packages. Visualization was carried out using the *ggraph* package. For additional background, we refer readers to prior publications (Golitko and Feinman 2015; Golitko *et al.* 2019; see also Golitko *et al.* 2012) that provide greater detail and depth than we have space for here.

We do not assume that the similarity networks constructed from obsidian source frequencies faithfully represent underlying transport networks, as they are intrinsically limited to the end distribution of obsidian and thus may miss intermediate transport links. Rather, we interpret the strength of ties between sites on the graphs, based on the similarity of their obsidian assemblages, as indicative of the probability of consequential economic engagement between pairs of sites (Golitko and Feinman 2015; Golitko *et al.* 2019). This analytical approach also yields metrics that permit quantitative comparison and assessment across time (see Golitko *et al.* 2019). Analytical visualizations of rich empirical archives are central to social scientific investigation (Healy and Moody 2014). We utilize these graphical tools as an empirical basis to draw conceptual and historical implications and to assess and evaluate long-held notions regarding the prehispanic Mesoamerican past and preindustrial economies more generally (Feinman and Nicholas 2012).

Obsidian Procurement Networks in the Ancient Mesoamerican World

Given the geographical concentration of obsidian sources in Central Mexico and the Guatemalan Highlands (Figure 8.1), it is not surprising that network clustering throughout the sequence generally reflects this pattern and that the graphs generally are visually divisible into two internally connected components with more limited east–west linkage across what is also a cultural/linguistic divide between the Maya (eastern Mesoamerica) and the rest of (western) Mesoamerica. Despite this basic bipartite pattern, the specific linkages between the two main subgraphs fluctuate, and we focus on these changes

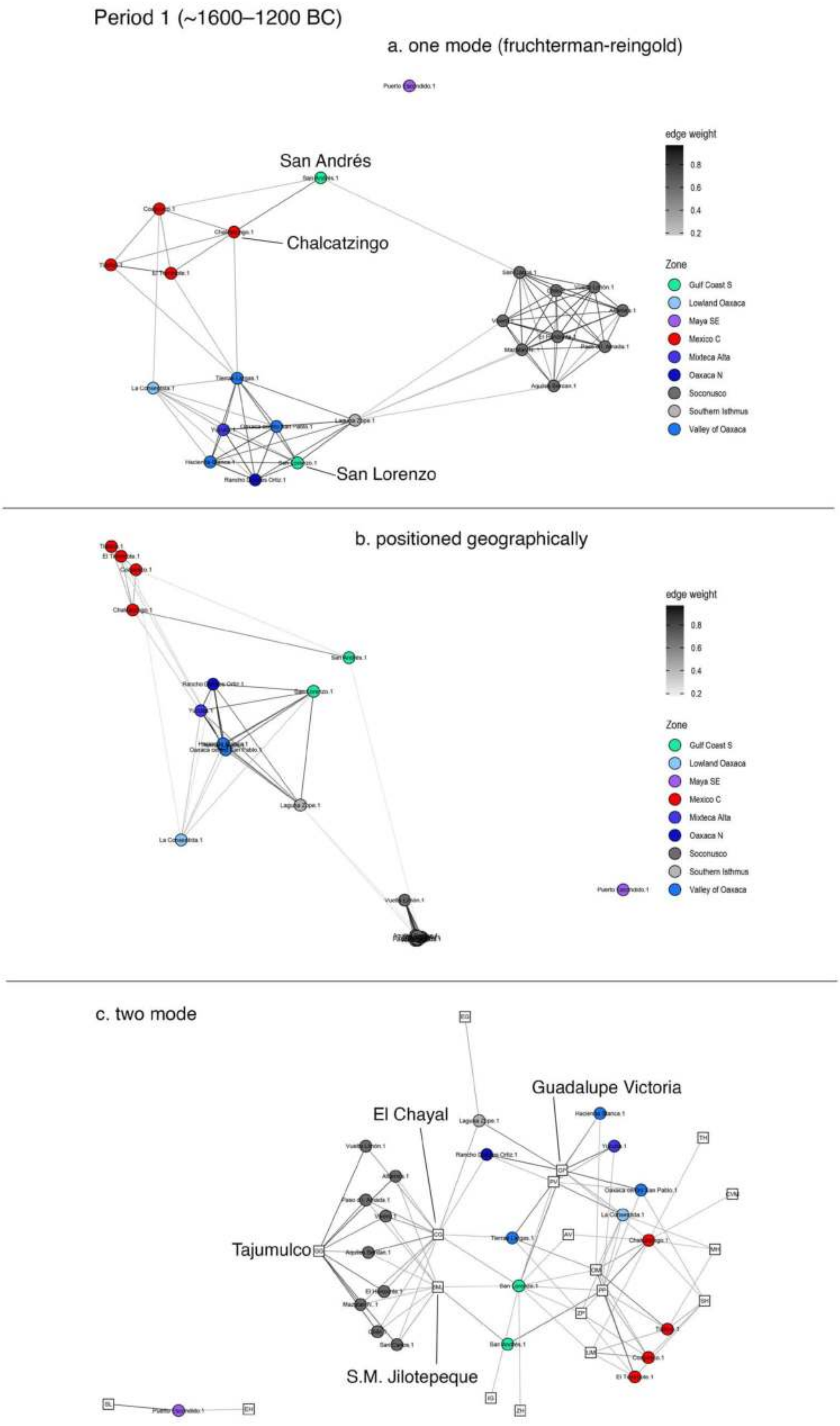

Figure 8.2. Network graphs for Period 1 (~1600/1500–1200 BC): a, one-mode graph; b, nodes positioned geographically; c, two-mode graph

Table 8.4. Movement of obsidian between western and eastern Mesoamerica

	Sites in Western Mesoamerica		Sites in Eastern Mesoamerica	
Period	western source	eastern source	western source	eastern source
P1	91.21%	8.79%	0.00%	100.00%
P2	93.80%	6.20%	0.00%	100.00%
P3a	88.48%	11.52%	0.01%	99.99%
P3b	89.93%	10.07%	0.09%	99.91%
P4a	97.33%	2.67%	0.20%	99.80%
P4b	99.49%	0.51%	0.29%	99.71%
P5	100.00%	0.00%	3.60%	96.40%
P6	99.90%	0.10%	9.11%	90.89%
P7	99.85%	0.15%	7.30%	92.70%
P8	99.99%	0.01%	5.99%	94.01%

over time. We also examine the placement of specific large centers in the graphs to see how their relative placement may impact obsidian procurement from one period to the next. We also consider the general topology or constituent properties of the network and how that shifted during the prehispanic sequence. The bipartite structure of the graphs might be seen as reflecting a general reliance on relatively more proximate obsidian sources, yet the diversity, or richness (Nelson *et al.* 2011), of obsidian at most sites, as well as the dynamism of the graphs across time, does not accord with acquisition of obsidian principally from the nearest source through local networks.

Early Formative (~1600/1500–900 BC)

From the earliest time block (~1600/1500–1200 BC), three separate clusters of sites are evident in the network graphs (Figure 8.2a–b). These largely conform to geography. The Gulf Coast sites are a significant exception. As part of different subgraphs, the two Olmec sites (for which we have data) link eastern Mesoamerica (Maya) to different western regions. Although Maya obsidian reached western Mesoamerica, we do not have any evidence that western sources reached eastern Mesoamerica at this time (Table 8.4, Figure 8.2c). The principal east–west link was along the Pacific Coast from the Guatemalan sources, through Soconusco and the southern Isthmus, to San Lorenzo Tenochtitlan (Ebert *et al.* 2014) and sites in highland Oaxaca. The other, weaker link was through San Andrés to Chalcatzingo and Central Mexico (Figure 8.2a–b). There was almost no overlap in the principal eastern sources that were exchanged along these two networks. The Maya source most widely traded to the west, El Chayal, moved along the southern network, mostly to San Lorenzo, almost 600km away, but also in low amounts to several sites in Oaxaca, more than 700km from the source. Most obsidian that reached highland Oaxaca was from Puebla/Gulf Coast sources (e.g., Guadalupe Victoria), less than 250km away. Another Maya source, San Martín Jilotepeque, traveled more than 500km to San Andrés on the Gulf Coast, but it did not reach Central Mexico. Obsidian from local sources predominated at the Central Mexican sites, but small amounts of Puebla/Gulf Coast obsidian were traded to most of them.

Obsidian distributions vary markedly in richness. In each network (or subgraph), a key western node obtained obsidian from a much wider array of sources than any other site in their respective networks (Figure 8.2c). In the more northern network, it was Chalcatzingo, an early center in eastern Morelos that was located on a longstanding trade route connecting the Basin of Mexico to areas to the south and east (Grove *et al.* 1976; Hirth 1987). In the southern network, it was San Lorenzo, which was the most influential center in the southern Gulf Coast (Hirth *et al.* 2013; Pool 2009). San Lorenzo was initially settled ~1800 BC, and prior to 1600 BC the entire obsidian assemblage at the site comprised pressure flakes, which mostly were worked from nodules from the nearest Puebla/Gulf Coast source, Guadalupe Victoria. Yet a small percentage of the obsidian came from El Chayal (Hirth *et al.* 2013: 2787–2789). After 1500 BC, finished blades were procured in small quantities (~6% of assemblage), almost entirely from new Central Mexican sources and El Chayal. Obsidian from the latter source increased to ~20% of the San Lorenzo assemblage (Hirth *et al.* 2013: 2789–2790).

Shifts in the networks are evident in the subsequent period (1200–900 BC); the northern network appears to have been severed as stronger links developed between regional clusters, including between highland Oaxaca and Central Mexico and between the eastern and western subgraphs through both San Lorenzo and

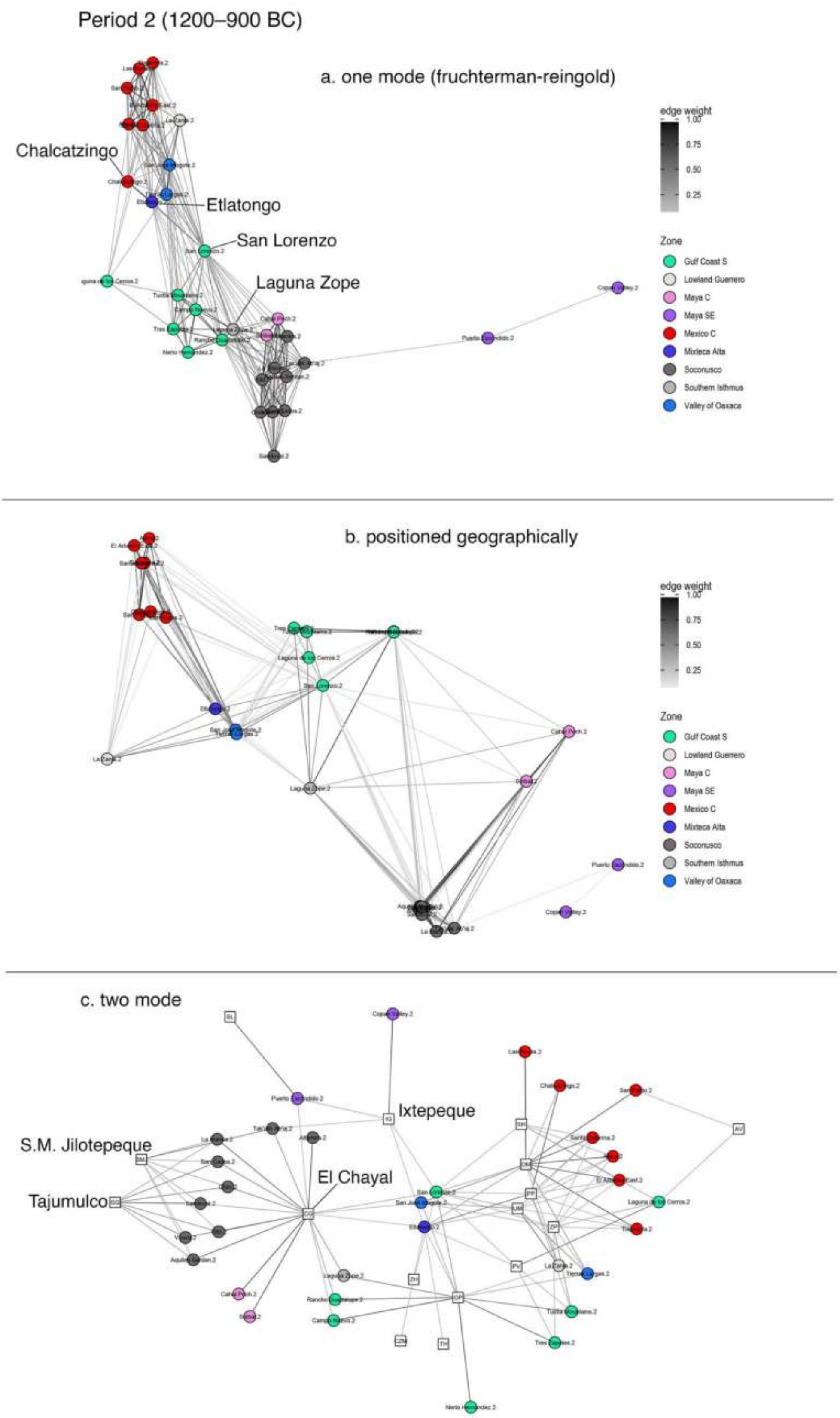

Figure 8.3. Network graphs for Period 2 (1200–900 BC): a, one-mode graph; b, nodes positioned geographically; c, two-mode graph

Laguna Zope (Figure 8.3a–b). Although the southern Isthmus continued to be a principal link between eastern Mesoamerica and the Gulf Coast, San Lorenzo became the central node in the west, establishing new links to eastern Mesoamerica and expanding networks to Chalcatzingo and sites in Central Mexico. Even with more interconnections between regions, there still was a stark variation in the richness of obsidian sources by site, with key nodes in the networks—San Lorenzo on the Gulf Coast and Etlatongo in highland Oaxaca—obtaining obsidian from three to four times as many different sources as neighboring sites in each region (Figure 8.3c). These changes align with the expanding size and monumentality of San Lorenzo and the active participation of the site's residents in interregional trade networks (Hirth *et al.* 2013).

Between 1200–900 BC, obsidian from eastern Maya sources continued to be traded west to San Lorenzo and Laguna Zope, with smaller amounts procured at other sites along the Gulf Coast and in highland Oaxaca (Figure 8.3c). Nevertheless, western sources still were not being moved east. The Maya source (San Martín Jilotepeque) that had passed through the earlier northern route was much less widely distributed, while those that had moved through the southern route (El Chayal, Ixtepeque) comprised the Maya obsidian that was transported west.

Tajumulco, a poor-quality obsidian mined near the Soconusco/Guatemala border, was used largely to make percussion flakes (Jackson and Love 1991: 53; Mendelsohn 2018: 637). This obsidian had been widespread in nearby Soconusco ~1600–1200 BC, but its utilization declined precipitously after 1200 BC as blade technology became more prevalent (e.g., Boksenbaum *et al.* 1987; Clark 1987; Ebert *et al.* 2014; Stark *et al.* 2016), and other obsidians more suitable for producing blades, including El Chayal, replaced Tajumulco as the dominant source in eastern Mesoamerica (Clark and Lee 1984). This shift also is evidenced at San Lorenzo, where the proportion of blades in the obsidian assemblage increased after 1200 BC, including blades of El Chayal obsidian (Hirth *et al.* 2013: 2791).

The patterns that we see for ~1600–900 BC accord with prior interpretations that obsidian moved through long-distance, competitive, elite networks (Hirth 1998; Stoner and Nichols 2019: 251). Emergent leaders at key sites, like San Lorenzo, were active agents in these networks. The production and acquisition of obsidian blades over that time was an increasingly important element in these rather linear, down-the-line reciprocal exchange networks (Clark 1987). The nodal significance of key sites, such as San Lorenzo and Etlatongo, in these exchange spheres indicates that their importance was not just subsistence-based and local. Rather, long-distance relations and the interregional movement of goods were key aspects of early settled life in Mesoamerica.

Middle Formative (900–300 BC)

After 900 BC, there were important changes in the movement, use, and even (in some contexts) the meaning of obsidian in Mesoamerica. In the early part of this period (900–600 BC), the northern network between the Gulf Coast and eastern Mesoamerica reemerged with the rise of La Venta (Berning 2016; Pool 2009) (Figure 8.4a–b). As before, the predominant transfer of obsidian moved from eastern sources to the west, with El Chayal obsidian continuing to travel through the southern network that linked San Lorenzo to the Pacific Coast through the Isthmus (Figure 8.4c). San Martín Jilotepeque obsidian once again moved along the northern network to La Venta. Overall, if you consider both networks, eastern obsidians comprised 10–12% of all western Mesoamerican assemblages in our sample, although the Maya obsidians were concentrated mostly in the Gulf Coast and the Isthmus.

The east–west bipartite structure of the graph is maintained but with somewhat less regionalization and greater interconnectivity within each subgraph. Visually, the links between sites in each subgraph were less linear, more interlinked than in the two prior time blocks. The average number of different sources at sites in both the west and east increased (from 3.9 to 5.2 in the west, from 2.4 to 2.9 in the east, Table 8.3). Central Mexican obsidian sources were transported east to the Gulf Coast in much greater quantities than before, with most Gulf Coast sites in the sample dominated by Central Mexican obsidian instead of obsidian from closer sources. Small amounts of Central Mexican obsidian also were procured at Pacific Coast sites, but little was transported beyond. The Gulf Coast sites continued to be principal nodes in these interregional trade networks, as they consumed obsidian from twice as many different sources than did sites in other western Mesoamerican regions, including most of the obsidian in the west that was acquired from eastern sources. But although the key Gulf Coast sites continued to have an important bridging position between the two subgraphs, they did not control or dominate the web of connections to the same extent as they had earlier (Table 8.3; Love 2007). The closer links that developed between highland Oaxaca and Central Mexico in the prior period continued.

In the subsequent period (600–300 BC), it is evident visually that neither San Lorenzo nor the Isthmus sites were as centrally positioned in the network as they had been earlier. The principal link between east and west was now through La Venta (Figure 8.5a–b), which

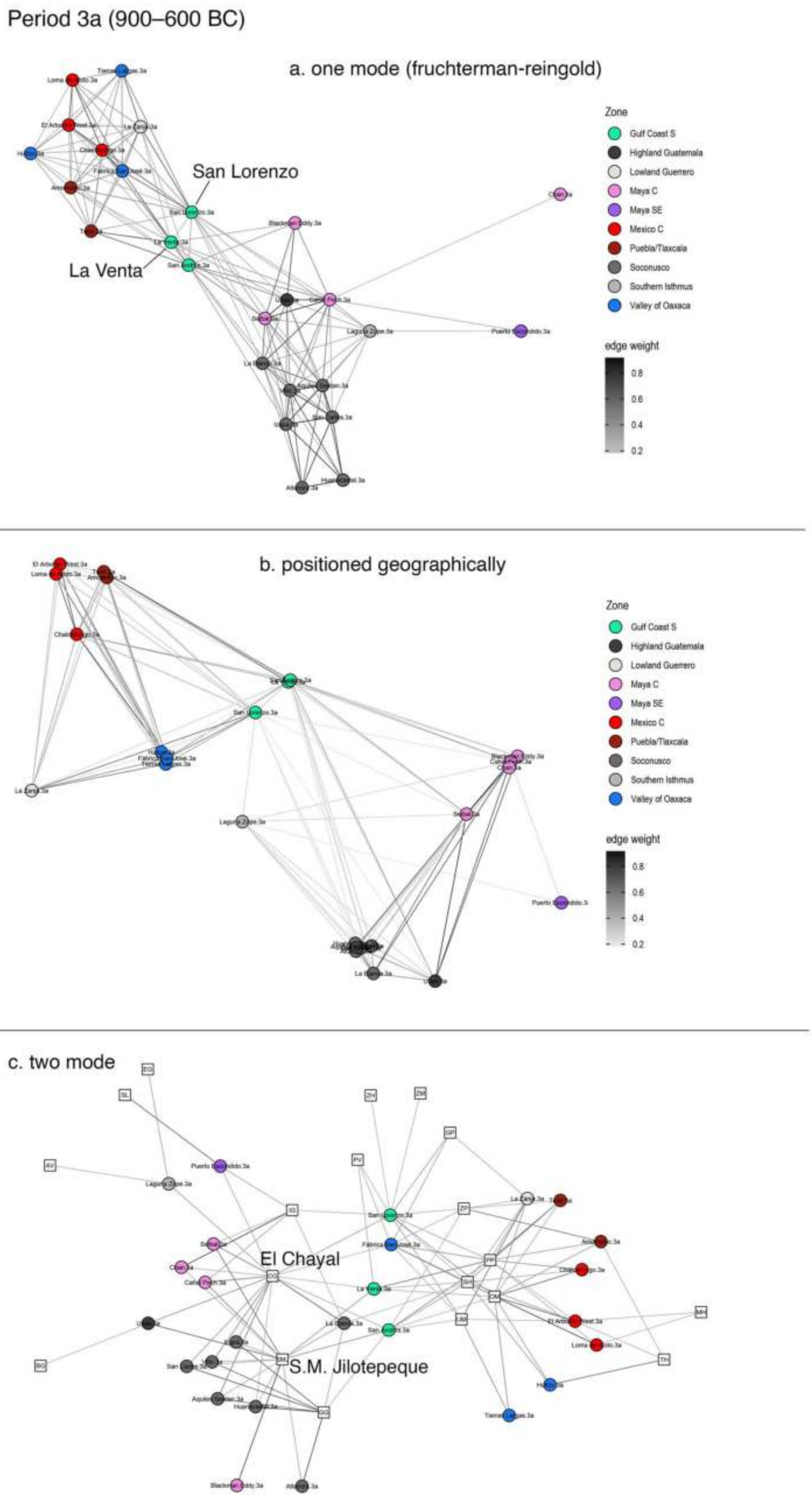

Figure 8.4. Network graphs for Period 3a (900–600 BC): a, one-mode graph; b, nodes positioned geographically; c, two-mode graph

surpassed San Lorenzo in size and importance (Berning 2016; Diehl 2004). Shifting exchange relations in the Maya region and between that region and the Gulf Coast may have been factors in La Venta's rise and San Lorenzo's decline. Obsidian from San Martín Jilotepeque greatly surpassed El Chayal in abundance throughout eastern Mesoamerica at this time. Concurrently, it also became more prevalent than El Chayal on the Gulf Coast and elsewhere in western Mesoamerica. A principal route for the movement of San Martín Jilotepeque obsidian to the Gulf Coast may have been through Seibal on the Usumacinta River in Guatemala (Aoyama 2017), where quantities of Jilotepeque surpassed El Chayal by an order of magnitude. Gulf sites continued to obtain greater quantities of obsidian from Central Mexican and Guatemalan sources than locally (Figure 8.5c), and Maya obsidian continued to comprise more than 10% of all sourced obsidian in western Mesoamerica (Table 8.4). As in earlier periods, there was still little western obsidian procured in eastern Mesoamerica.

The graphs continue to show a decline in regionalization, especially in the western subgraph, as more interconnections are evident between sites located in different regions. The change in network structure from a more linear arrangement to a more interconnected structure along with more continuous distributions of the number of obsidian sources per site in western Mesoamerica (the average number of different sources per site rose to a high of 6.2, Table 8.3) together provide indications of a shift in the modes through which obsidian was transferred in Mesoamerica.

As an example, there are no obsidian sources in the entire state of Oaxaca, yet sites in highland Oaxaca overall have as high a diversity of sources (6.9) as the Gulf Coast centers. For this period in our sample, two sites in the Valley of Oaxaca (Monte Albán, Fábrica San José) procured obsidian from the greatest number of distinct sources (11), including material from Puebla/Gulf Coast, Central Mexico, West Mexico (Michoacán), and Guatemala. The rich diversity of obsidians consumed in Oaxaca signals the growing connectedness of Mesoamerica at this time.

During the span of the Middle Formative, there was a much greater proportion of obsidian that was worked into blades (e.g., Clark 1987; Hirth 2012; Hirth *et al.* 2013). The replacement of percussion flakes by prismatic blades indicates more efficient tool production, as more cutting edge was created per material weight (Clark 1987: 269–270). Blades and cores were more efficient to transfer than nodules especially if traders engaged in multiple transactions per journey. The increasing preeminence of this technology facilitated long-distance trade (Boksenbaum *et al.* 1987; Stark *et al.* 2016), and blades began to be exchanged extensively (De Leon *et al.* 2009; Hirth 2012). Blade making was one element in the expansion of craft specialization that was associated with the growth of large centers across Mesoamerica (e.g., Feinman 1986). Settlement nucleation often entailed greater degrees of domestic interdependence (in part as a means to buffer risk) and the consumption of more goods that households did not produce themselves (Feinman and Nicholas 2012). The importance of obsidian blades at this time is signaled by their inclusion in key ritual contexts and caches, sometimes in lieu of the green stone axes that were placed in such contexts earlier (Aoyama *et al.* 2017).

Although the patterns in the graphs and the imbalanced distributions of obsidian in prior periods illustrate the unequal and long-distance movement of most goods in linear networks of down-the-line exchange, the changes in the graphs after 600 BC to more interconnected networks with an increased number of links between subgraphs, and more even distribution of obsidian richness across nodes are indications of a transition in modes of transfer. Higher intensities of exchange along with wider, more-interconnected networks of economic transaction have been seen as indicators for marketplace exchange networks (Feinman and Garraty 2010; Hirth 1998: 454–455, 2012; Renfrew 1975: 42; Stark and Garraty 2010). For at least one region of highland Mesoamerica at this time, the emergence of markets has long been proposed, albeit based on different, supporting suites of empirical evidence (e.g., Feinman *et al.* 1984; Winter 1984).

When we make the case for the importance of marketplace exchange, we stress that we are not suggesting that such markets were necessarily "free" or entirely untethered from institutions of governance. Marketplace transactions require cooperation, rules, and degrees of enforcement, all of which indicate a role for governance (Blanton 2013). Globally, the nature of the interplay between governance and markets is highly variable and cannot be our main focus here given the diversity of articulations across Mesoamerica and more globally (Feinman and Garraty 2010; Feinman and Nicholas 2021; Garraty and Stark 2010).

Late/Terminal Formative (300 BC–AD 300)

At the scale of the overall cultural region (Mesoamerica), the basic east–west bipartite structure is preserved during this era. In the Late Formative (300 BC–AD 1), links between east and west continued through the Isthmus to the Pacific Coast and through La Venta to the Petén Maya, but the latter links were not as strong as before (Figure 8.6a–b). Although La Venta's network continued to procure obsidian from San Martín Jilotepeque, and El Chayal material was traded through

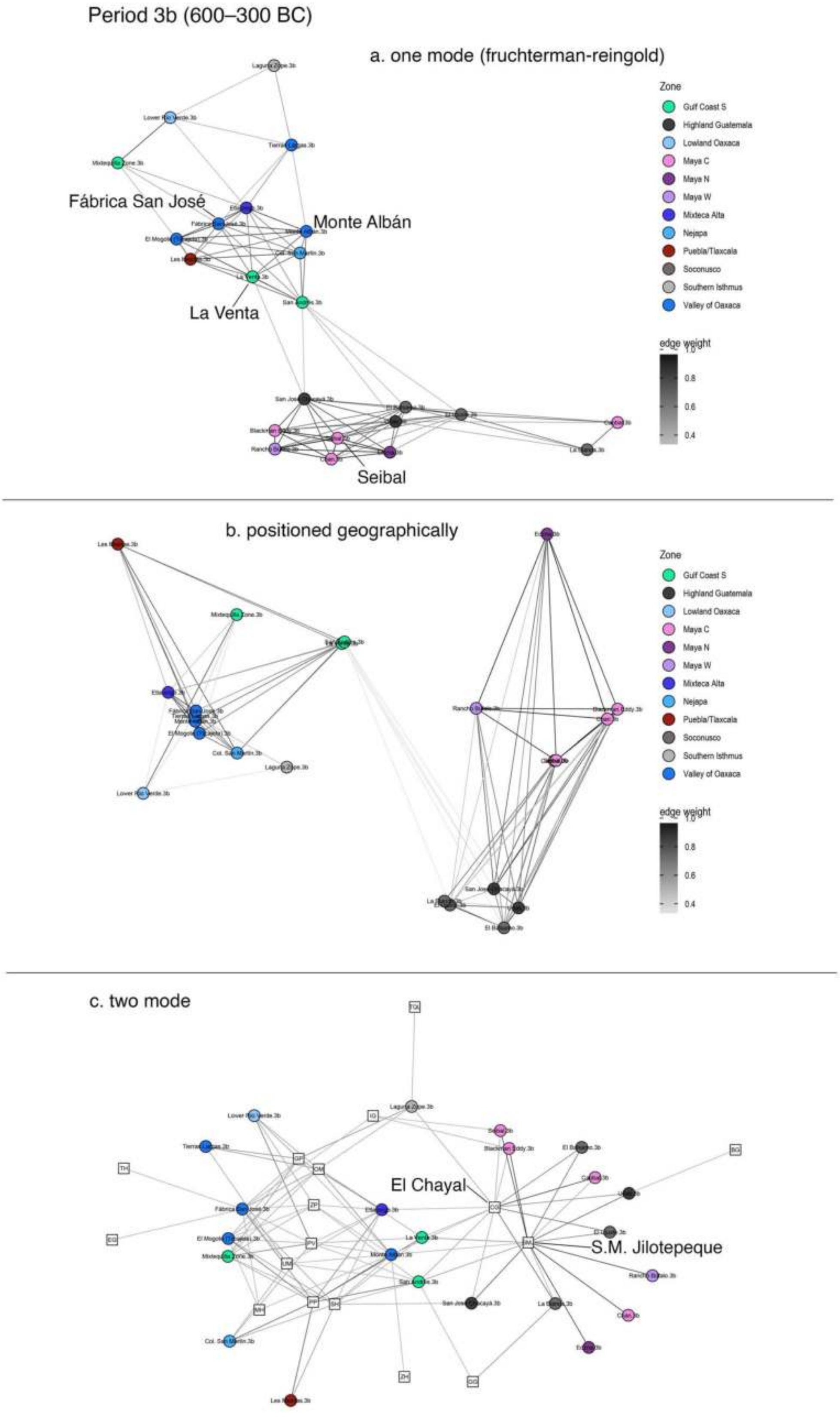

Figure 8.5. Network graphs for Period 3b (600–300 BC): a, one-mode graph; b, nodes positioned geographically; c, two-mode graph

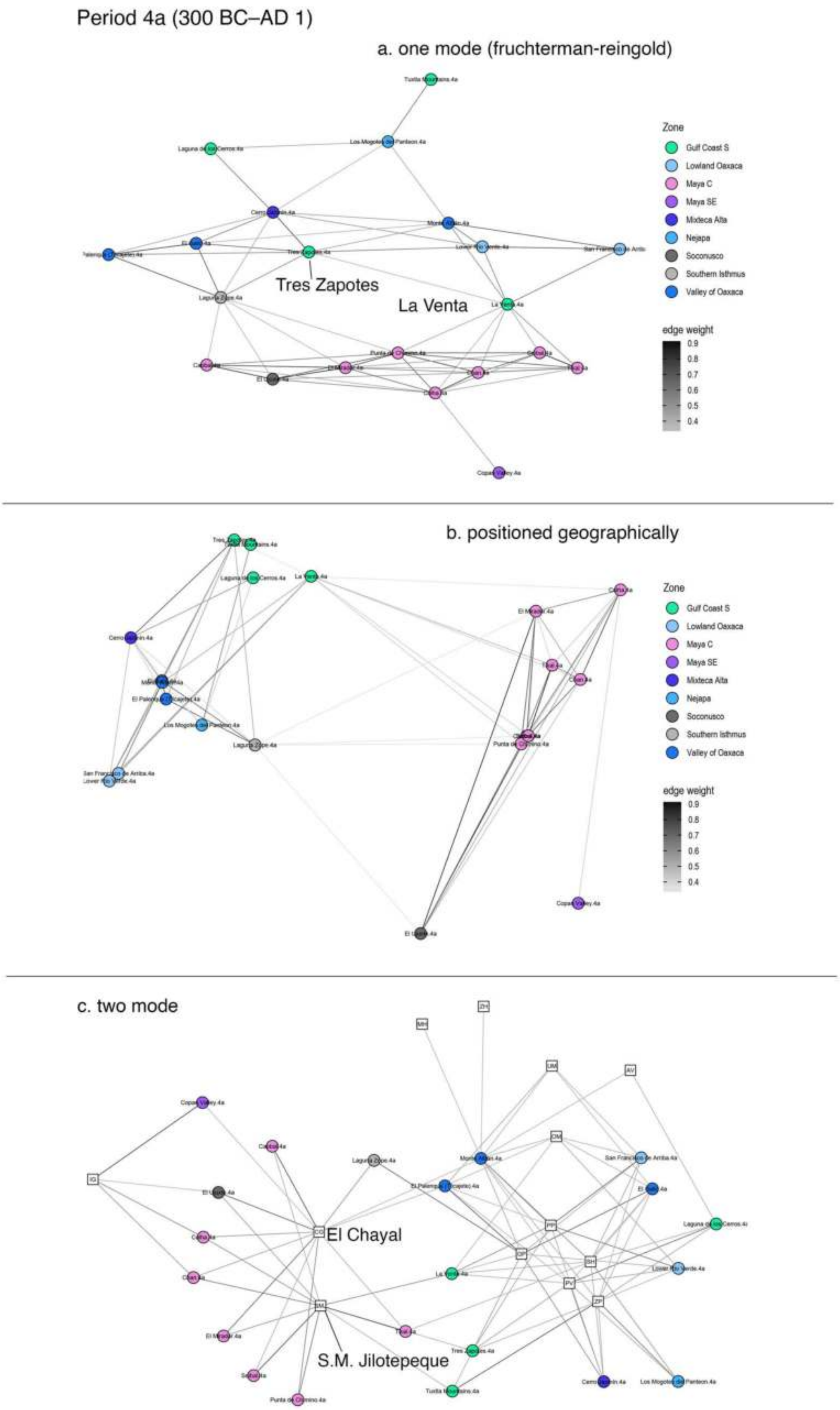

Figure 8.6. Network graphs for Period 4a (300 BC–AD 1): a, one-mode graph; b, nodes positioned geographically; c, two-mode graph

the Isthmus to then reach highland Oaxaca (Figure 8.6c), the quantity of eastern obsidian moving to the west declined significantly from earlier periods, so that it constituted only ~2.7% of western Mesoamerican assemblages. Although only minute amounts of western obsidian were reaching eastern Mesoamerica, this was a slight tick up from prior periods (Table 8.4). At the same time, the lattice of interconnections across regions in the west strengthened further. Sites in Oaxaca continued to have the highest average number of sources per site (Figure 8.6c).

Gulf sites continued to have a mix of obsidian from Central Mexican and Puebla/Gulf Coast sources, but the decline in Central Mexican obsidian relative to closer obsidian sources serves as an indication of the Gulf's less central role in panregional obsidian exchange. Between ~1600–300 BC, San Lorenzo and La Venta had been principal nodes in obsidian exchange across the Gulf Coast and beyond, capitalizing on external relations to bring obsidian from Central Mexico and Guatemala to the Gulf Coast. Between 300 BC–AD 1, the large Olmec centers, including La Venta, had declined and lost their role as central nodes in interregional exchange networks, while Tres Zapotes expanded to become the largest center on the Gulf Coast (Pool *et al.* 2014: 276). Situated near the coast but far to the west, Tres Zapotes had previously been peripheral to exchange networks through La Venta and San Lorenzo and received only limited amounts of obsidian from Central Mexico; no obsidian from Guatemalan sources reached the site. Instead, Tres Zapotes exploited mostly local sources, although the residents of the site began to acquire limited amounts of obsidian from San Martín Jilotepeque after 300 BC. Tres Zapotes has been viewed as more collectively organized than either earlier San Lorenzo or La Venta. As a consequence, reliance on the external networks, broken by the decline of La Venta, was not reestablished. Tres Zapotes continued to procure obsidian mostly from Puebla/Gulf Coast sources (Pool *et al.* 2014: 276).

For the later Terminal Formative (AD 1–300), the overall graph is more strongly bipartite, consisting of two intensively interconnected subgraphs (east and west) that were very weakly linked along the Pacific Coast through the Isthmus (Laguna Zope and El Carrizal) (Figure 8.7a–b). The Gulf Coast sites were no longer central nodes in obsidian exchanges between east and west. The lack of connection between the two subgraphs also is visible in the much lower amounts of obsidian moving across the east–west boundary. The quantity of eastern obsidians moving to the west declined significantly (~0.5% of western assemblages), although minute amounts still reached the Isthmus, the Gulf Coast, and highland Oaxaca (Figure 8.7c). Western obsidians still did not move east in any significant quantities (~0.3% of eastern assemblages). From a holistic perspective, less obsidian was transferred across the western-eastern Mesoamerican divide during this time block compared to any other.

Yet the eastern subgraph had greater internal connectedness compared to earlier periods, which likely is indicative of greater levels of exchange and interaction between sites in the Maya Lowlands (Blanton *et al.* 1993: 173; Freidel 1979). The degree of internal connectedness also increased in the western subgraph, with Oaxaca, especially Monte Albán, the recipient of obsidian from all principal western sources (Figure 8.7c). These graphical patterns appear to reflect the presence of two market networks that were only minimally interlinked. With the increasing integration of regional market systems in the west, especially across the highlands, there was less dependence on exchange with the Maya, thereby helping account for the decline in Maya sources traded to the west.

The decline in eastern obsidians moving west presages another shift that occurred after AD 300. By the end of this period (~AD 300), there was increasing long-distance movement of what have been termed, "bulk luxuries," goods such as cotton cloth, obsidian, feathers, cacao (Blanton *et al.* 2005). The movement of these goods and changes in obsidian blade exchange may be related. Teotihuacan was founded and rose to great size in the Basin of Mexico during this period (Cowgill 2015). Yet, the site did not have a central position in the network, and we see little support for the argument that its occupants had monopolistic control over the long-distance flows of obsidian. At Monte Albán, in the Valley of Oaxaca, the obsidian assemblage had been dominated by Central Mexican sources for several hundred years well before Teotihuacan was founded in the Basin of Mexico ~100 BC.

Early Classic (AD 300–600)

Changes in the graphs after AD 300 reflect significant transformations in macroregional relations and networks. The one-mode graph is less strongly bipartite than during any earlier period and consists of three principal subgraphs (Figure 8.8a). Subsets of sites in highland Oaxaca and on the southern Pacific Coast visually form a subgraph with Teotihuacan that bridges two more internally connected subgraphs, one that includes the eastern Mesoamerican sites and the other that was composed mostly of sites in the eastern arm of the Valley of Oaxaca and along the Gulf Coast. The main bridging links between eastern and western Mesoamerica remain, as prior to AD 300, along the Pacific Coast of Oaxaca through Soconusco

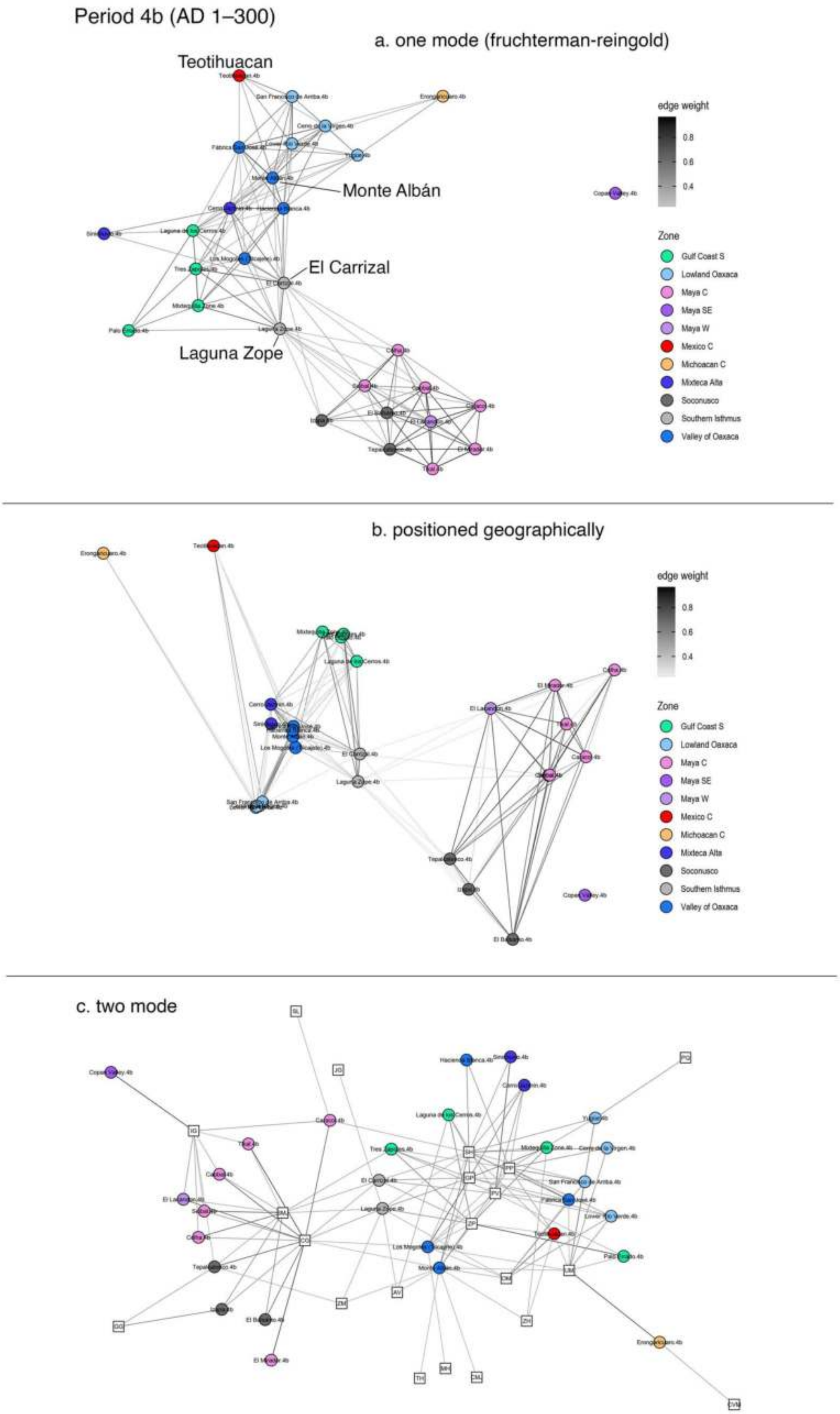

Figure 8.7. Network graphs for Period 4b (AD 1–300): a, one-mode graph; b, nodes positioned geographically; c, two-mode graph

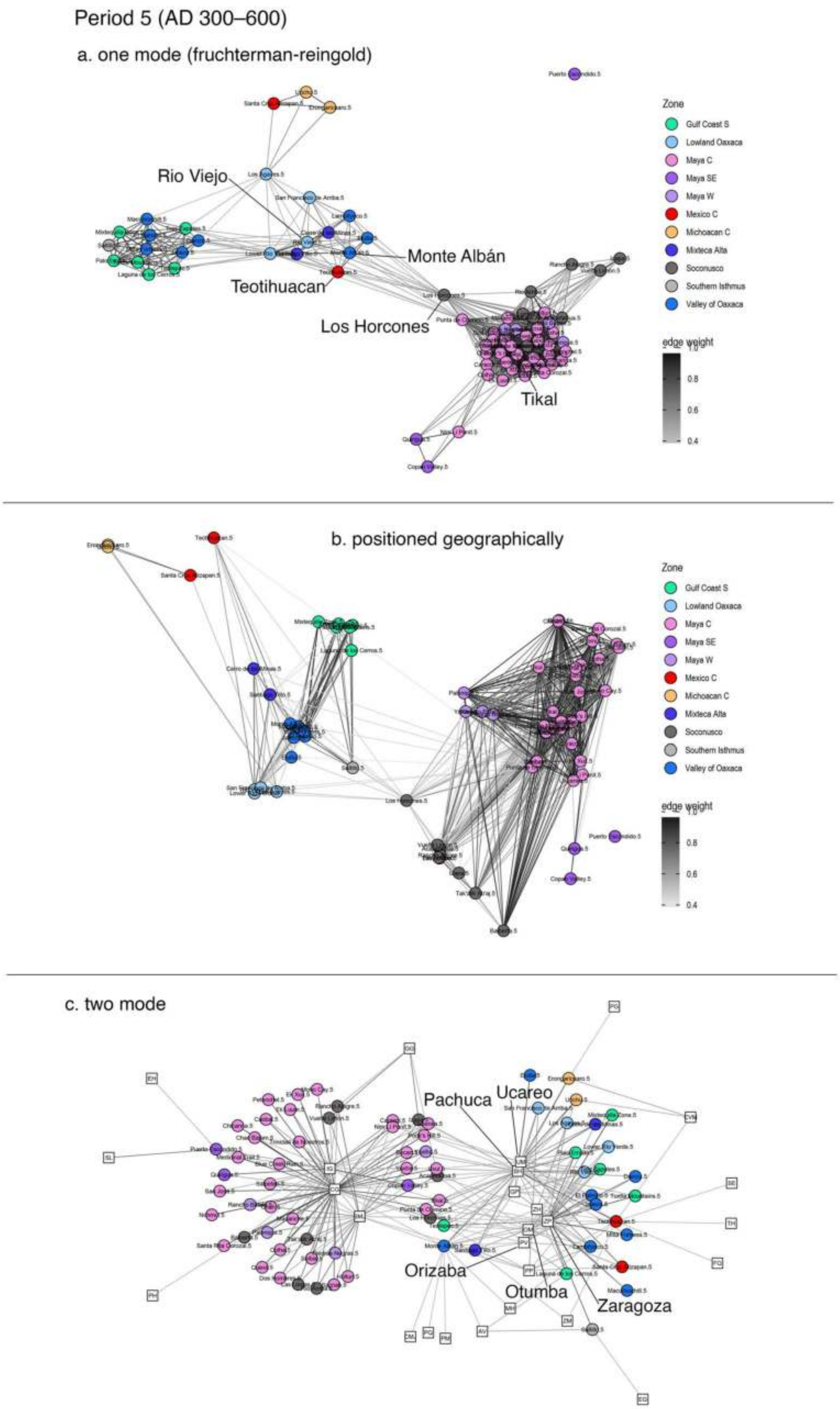

Figure 8.8. Network graphs for Period 5 (AD 300–600): a, one-mode graph; b, nodes positioned geographically; c, two-mode graph

(Figure 8.8b), although some movement through the Gulf Coast also likely occurred (Golitko and Feinman 2015: 223).

The central, linking cluster, which includes Teotihuacan and Monte Albán, also is tied closely to Rio Viejo on the Oaxaca coast (Joyce *et al.* 1995), a third site that is part of the bridging subgraph, which in turn was linked to the Maya region through the Pacific Coast "gateway" community of Los Horcones (García-Des Lauriers 2012; Golitko and Feinman 2015: 222). For the period after AD 300, these links in the graph align with documented relations between Teotihuacan and Monte Albán (Marcus 1983), the Oaxaca coast (Rivera Guzmán 2011), Tikal in northern Guatemala (Sugiyama *et al.* 2020; Wade 2020), and Kaminaljuyu in the Guatemalan Highlands (Sanders and Michels 1977). We previously proposed that through these external contacts, Teotihuacan emissaries may have disseminated specific facets of calendric knowledge as a means to "pressure" and facilitate the synchronization of marketplace activities across most of Mesoamerica (Feinman and Nicholas 2020). The greater degrees of economic interconnection fostered by a temporal alignment and integration of market networks may help account for the marked increases in the long-distance flows of bulk luxuries.

Based on the two-mode graph for the Early Classic (Figure 8.8c), there is a marked change in the directionality of obsidian flows across Mesoamerica. Instead of eastern Mesoamerican (Maya) obsidians moving west as occurred earlier, after AD 300 material from western Mesoamerican sources were transported into the Maya region. Green obsidian from Pachuca is the most widespread and abundant of these, especially at Tikal (Moholy-Nagy *et al.* 2013); however, obsidian from other western Mesoamerican sources, including Ucareo, Pico de Orizaba, Zaragoza, Otumba, and others also were transferred east. As these obsidian sources are dispersed across western Mesoamerica, we do not see this directional shift as indicative of any one site, namely Teotihuacan, centrally controlling Early Classic obsidian flows. At the same time, eastern obsidian sources now rarely were conveyed to western Mesoamerica.

We also do not see a change in either technology or specific obsidian resources as the key factor in this shift. The same primary sources of obsidian were exploited, and prismatic blade technology extends back well before the Early Classic (Awe and Healy 1994; Jackson and Love 1991). The intensity and volume of obsidian production at Teotihuacan (Carballo 2013) may have had an impact on the reversed directionality of long-range flows, although seemingly more as a consequence than a cause. Alternatively, the directional reversal in the flows of obsidian could reflect the increasing importance that specific lowland commodities, namely cotton, feathers, and cacao, achieved in western Mesoamerica by the Early Classic period (Blanton *et al.* 2005), which shifted networks and flows for other goods (e.g., obsidian).

Across Mesoamerica, most ceramic figurines were elaborately dressed by the Classic period, whereas earlier ones were typically represented nude (Blanton *et al.* 2005; Stark *et al.* 1998). Classic period mural and tomb paintings at highland sites also portray elaborately attired figures (e.g., Carballo 2013; Miller 1995). At the same time, increasing investments in cotton spinning and weaving (indicated by durable tool kits) have been established for several regions during this period (Hall 1997; Halperin 2008; Hirth and Villaseñor 1981; Stark *et al.* 1998). Elaborate forms of woven attire served as markers of roles and status, as it did later during Aztec times (e.g., Berdan 1987). By the Classic period, greater quantities of cotton and cloth were transferred from lowland to highland regions of Mesoamerica. Although the volume of feathers and cacao that were moved east to west across Mesoamerica is more difficult to discern (since both are perishable goods), the increasing symbolic significance and representation of feather headdresses on ceramic figurines and vessels, murals, and other art exceeds what was represented earlier (e.g., Sugiyama 2000). In addition, cacao is depicted on Classic period pottery from the Valley of Oaxaca (Kowalewski *et al.* 1978: 188) and Teotihuacan (Coe and Coe 1996: 54). Ceramic cylindrical vases, a vessel form associated with written glyphs that represent cacao and its consumption among the Classic Maya (McAnany and Murata 2007), are more commonly found in highland regions by the onset of the Classic period (e.g., Caso *et al.* 1967: 297–299). For more than a millennium after the onset of the Classic period, cotton, cacao, and feathers all were imported in large quantities from lowland regions to the highlands (e.g., Smith 2003).

Late Classic (AD 600–900)

Changes in the graphs after AD 600 reflect another suite of transformations in panregional relations and networks. The one-mode graph resumes a more bipartite structure (as before AD 300–600), but with changes in the eastern and western subgraphs. In the eastern subgraph sites were more tightly clustered in a web of internal connections, and sites in southeastern Mesoamerica were more linked into the networks than ever before (Figure 8.9a). The western subgraph also had stronger internal connections, with sites in highland Oaxaca closely linked to Puebla and the Gulf Coast, and, for the first time, sites in Michoacán/West Mexico were more interconnected with sites in Central Mexico.

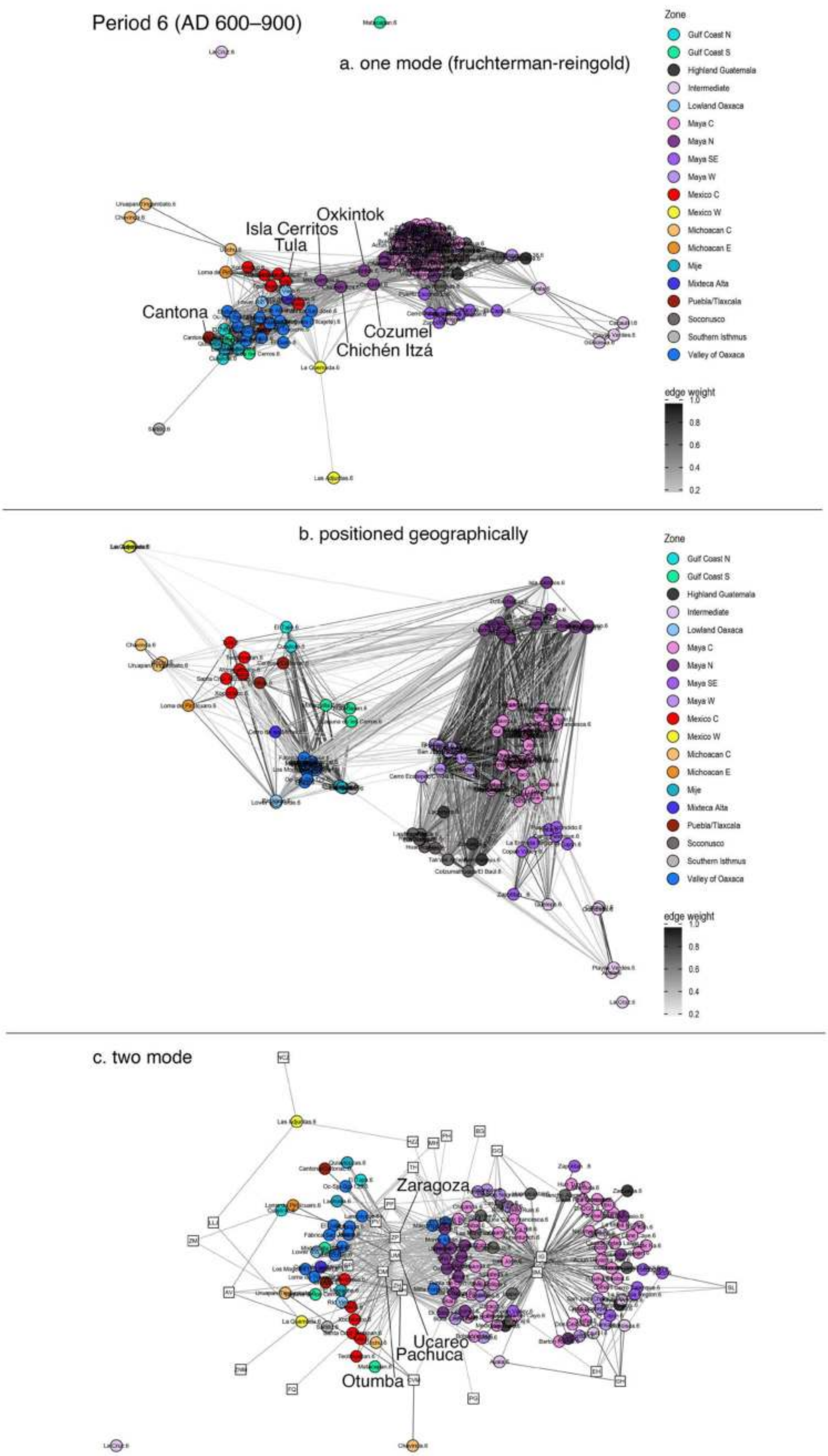

Figure 8.9. Network graphs for Period 6 (AD 600–900): a, one-mode graph; b, nodes positioned geographically; c, two-mode graph

The key change in the graphs, however, is the crucial bridging position of Chichén Itzá and associated settlements (Isla Cerritos, Oxkintok) in the northern Yucatán (Figure 8.9a–b) as connectors between the eastern and western Mesoamerica subgraphs. The northern Yucatán settlements have strong network ties to settlements in Oaxaca and Central Mexico, especially Tula (Healan 2007; Kowalski and Kristan-Graham 2007). Through these networks they obtained obsidian from as far away as 1200km (Ucareo in Michoacán). The Gulf Coast sites continue to be less central to the networks. At the same time, the Pacific Coast link, important before AD 600, is no longer significant, while Cozumel, off the eastern coast of Yucatán, also has a key bridging position indicative of the expanded role for long-distance Gulf water-borne trade (Golitko *et al.* 2012).

Yet inland foot transport must account for the tight internal connectivity of sites in Oaxaca, Puebla, and the Gulf Coast (Figure 8.9a). This net of relations centered on obsidian from Zaragoza (Figure 8.9c). Zaragoza had not been a major source beyond the Gulf Coast and parts of highland Oaxaca before AD 600. After Teotihuacan declined ~AD 550–700, Cantona, a competing settlement in eastern Puebla near the Zaragoza obsidian source, became the largest urban center in the Central Mexican Highlands (García Cook 2017; García Cook and Merino Carrión 1998). Cantona's inhabitants exploited Zaragoza obsidian (García Cook 2003: 315, 339) and established long-distance exchange connections across a broad area (García Cook and Merino Carrión 1998). Not only did Zaragoza become the dominant source in highland Oaxaca and throughout the Gulf Coast, but it was exchanged to sites as far away as the Yucatán Peninsula in eastern Mesoamerica.

Zaragoza was not the only western obsidian that moved east in greater quantities, as the reversal in the directionality of obsidian transfers from predominantly east-to-west to west-to-east intensified after AD 600, when as much as 9% of the obsidian at eastern Mesoamerican sites was from western sources (Table 8.4). In addition to Zaragoza, the Pachuca, Ucareo, and Otumba sources all were situated in bridging positions in the two-mode graph, as more than half of eastern Mesoamerican sites, especially in the northern Yucatán, obtained at least small amounts of western obsidians (Figure 8.9c). Pachuca obsidian was linked more intensely with Maya sites than it had been prior to Teotihuacan's decline, so there is little support for the hypothesis that governors of the latter site somehow controlled the long-distance distribution of large amounts of Pachuca obsidian.

Early Postclassic (AD 900–1200)

In the Early Postclassic graphs, we see a lower-density, fragmented version of the Late Classic network. The main bridge between eastern and western Mesoamerica still runs through the northern Yucatán (Isla Cerritos, Vista Alegre), which likely reflects late occupation at Chichén Itzá, still inhabited for the first century of this time block (Andrews *et al.* 2003) (Figure 8.10a–b). Based on strong ties between the northern Yucatán and areas as far south as the Chiapas/Guatemala coast and Cihuatan (El Salvador), in conjunction with the former's strong connections to Central Mexico (and also Oaxaca), we see broad panregional links from nodes in a graph at a scale not seen earlier. We suspect that the increasing importance of Gulf water-borne trade was a key factor underpinning the number of lengthy edges linked to the nodes in the northern Yucatán. Without Isla Cerritos and neighboring sites, and likely after the first century of the Early Postclassic (~AD 1000), the connections between eastern Mesoamerica and highland western Mesoamerica would have been weaker. The rest of the Maya world was less connected to western Mesoamerica, with no links of any strength connecting the southern Isthmus with the Chiapas/Guatemala coast (Figure 8.10b).

When obsidian was transferred between eastern and western Mesoamerica, the principal movement continued to be mostly from west-to-east, with 65% of eastern sites getting at least low amounts of obsidian from western sources. Obsidian from Pachuca, Ucareo, and Zaragoza were the sources that most linked the western to the eastern subgraph (Figure 8.10c), and a major route went from Tula to Isla Cerritos (Healan 2007). Despite this link, the connectivity of the graphs is markedly reduced compared to the Late Classic, a probable consequence of the decline and abandonment of many Late/Terminal Classic period Mesoamerican centers, such as Tikal and Monte Albán. Although the degree of connectedness across Mesoamerica decreased significantly at this time, the basic spatial positioning of the network links did not shift dramatically from the previous period (Golitko and Feinman 2015: 226).

Late Postclassic (AD 1200–1520)

The Late Postclassic graphs differ from earlier periods in that they do not have a strong dichotomous structure with two subgraphs that divide the sites between eastern and western Mesoamerica (Figure 8.11a). Rather, the network is subdivided into a series of smaller, tightly interconnected, geographically oriented subgraphs. The structure is more modular with subgraphs made up of sites from West Mexico, the Central and Southern Highlands, Guatemalan Highlands, Soconusco/Pacific Coast, and Maya Lowlands. At the same time, the overall connectivity of the graph is greater than earlier. Even though slightly fewer obsidian sources were exploited after AD 1200 than during the previous 600 years (Table 8.3), the average number of different obsidian

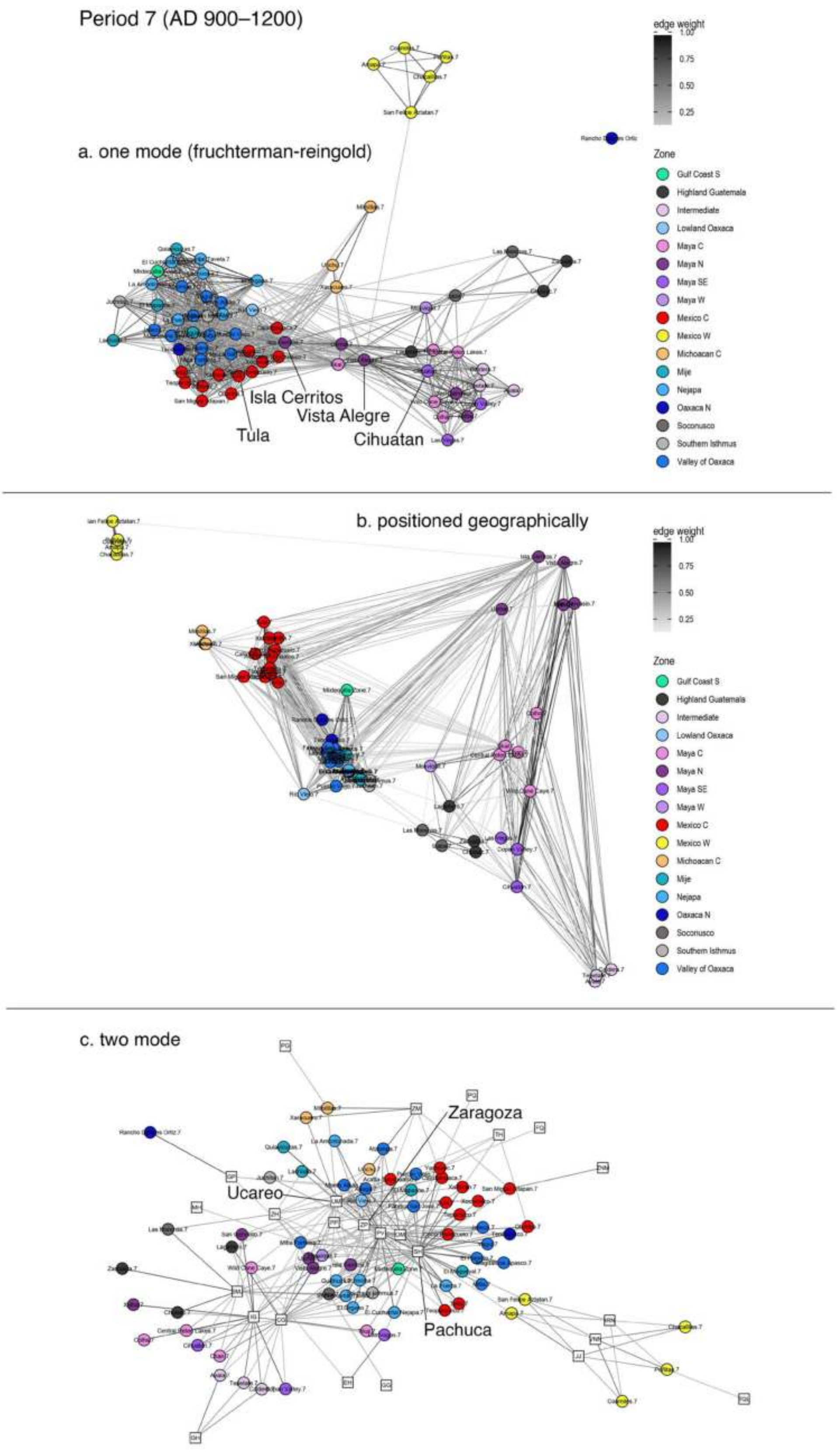

Figure 8.10. Network graphs for Period 7 (AD 900–1200): a, one-mode graph; b, nodes positioned geographically; c, two-mode graph

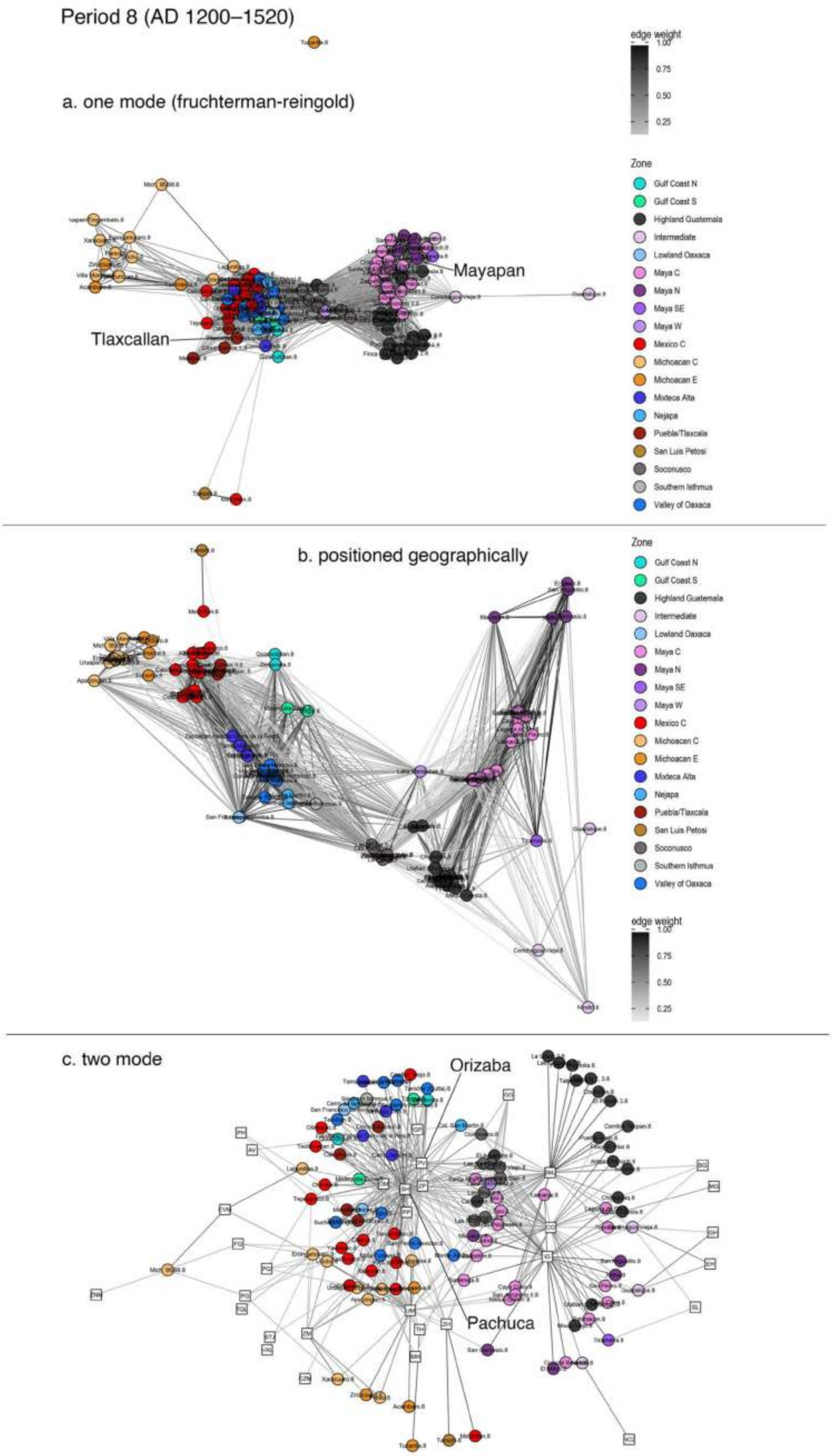

Figure 8.11. Network graphs for Period 8 (AD 1200–1520): a, one-mode graph; b, nodes positioned geographically; c, two-mode graph

sources per sampled site was roughly comparable to the Early Postclassic and less than in the Late Classic. So, although this network in its entirety was tightly interconnected, some sites were not, such as Tlaxcallan (Millhauser *et al.* 2015), which was an enemy of the Aztec empire and may have been politically estranged from certain interactions (Figure 8.11a–b). Likewise, the West Mexican subgraph, mostly associated with the Tarascan empire, is not as tightly linked to the rest of the network (Pollard 2003; Pollard and Smith 2003). Furthermore, obsidian from western sources declined precipitously at sites in northern Yucatán during the Late Postclassic, so this area may not have been as affected by increasing commercialization as were regions to the west.

The major bridges between eastern and western Mesoamerican subgraphs shifted back to the Pacific side after more than a half millennium when connections were stronger along the Gulf Coast (Figure 8.10b). Although maritime transport along the eastern coast of the Yucatán Peninsula remained important (Golitko *et al.* 2012), there is no evidence in the graphs that this transport continued around the northern end of the peninsula following the earlier declines of Chichén Itzá and Isla Cerritos. The preeminent northern Maya center of the time, Mayapan (Milbrath and Peraza Lope 2003), links principally to the south and has no direct ties to sites in western Mesoamerica, and sites in northern Yucatán had a lower average number of sources (2.8) than sites elsewhere in eastern Mesoamerica (3.5–3.8). Although the movement of obsidian from western Mesoamerican sources (especially Pachuca and Orizaba) to eastern Mesoamerica continued, most frequently to sites in Chiapas (Figure 8.11c), the relative quantities were lower than they had been during the Late Classic when maritime trade to the west had been more active.

From our perspective, the loss of connectivity and the local reorganizations evident in the Early Postclassic graphs (Figure 8.10) led to the forging of new socioeconomic routes and relations as old ties were lost or disrupted (Smith and Berdan 2000: 284). Likewise, as the Aztec stitched together an imperial realm (Berdan 1985, 1994; Blanton and Fargher 2012; Gasco and Voorhies 1989; Gutiérrez 2013), new tributary demands and interregional commercial links were established likely prompting realignments of the pan-Mesoamerican economic network (Figure 8.11). The new network topology dovetails with the long-held perspective that Late Postclassic Mesoamerica was different from earlier Mesoamerican worlds (e.g., Blanton *et al.* 2005), more commercialized and characterized by greater intensities of commodity movement than earlier in the prehispanic era (Blanton and Fargher 2012; Blanton *et al.* 2005; Blanton and Feinman 1984; Smith and Berdan 2000).

Concluding Thoughts

The network analysis of sourced Mesoamerican obsidian draws into question the key tenets broadly applied to premodern economies—that they were local, spatially bounded, and basically static. Obsidian was not only transferred across Mesoamerica from the beginning of settled life, but obsidian procurement and use generally was not strictly focused on materials from the one or two most proximate sources to each site. Across time, obsidian was moved far from source and often in considerable quantities, and, particularly in western Mesoamerica, where a wider range of sources was available, multiple obsidian sources generally were found at most sites during a given period. Based on these findings, we find it hard to imagine that Mesoamerican obsidian exchange was dominated by strictly or mostly local use and procurement. The long-distance movement of obsidian across Mesoamerica was important throughout the prehispanic era, although the paths and the modes of transfer were anything but static.

The main connecting routes between eastern and western Mesoamerica vacillated frequently between the Pacific and Gulf Coasts. This dynamism is indicative of fluidity in long-distance relations and flows across prehispanic Mesoamerica. We see the weakening of the dichotomous structure of the graphs through time as indicative of the increasing role of extra-regional interactions during the Classic and Postclassic periods (e.g., Blanton *et al.* 2005). Yet the later graphs are all configured in very different ways, another indicator of the dynamism of these relations, rather than stasis and localism.

The broad shift in obsidian flows from predominantly east-to-west during the Formative era (~1600 BC–AD 300) to principally west-to-east later in the sequence (AD 300–1520) is likely the result of shifts in the flows of other goods. We hypothesize that expanding highland demands for cotton, feathers, cacao, and possibly other lowland goods was a key factor contributing to the flow of western obsidian to the east. The shifting importance over time of obsidian exploited from different mines and the varying directions and paths through which they were transferred are additional axes of temporal diversity and change.

Although we cannot directly investigate specific modes of transfer or means of production (but see Carballo 2013; Feinman and Nicholas 2012; Feinman *et al.* 2013), the changing structure of the networks offers clues. We do not see any support for a model (e.g., Sanders and Santley 1983; Santley 1983) in which the rulers of large centers, situated near obsidian sources, controlled the distribution of that obsidian over broad areas. No one source dominated the graphs of any period. Rather, the network structure in earlier periods was more linear in nature, with central nodes that had a much higher diversity of sources than other sites in the network, a pattern in line with down-the-line exchange through competitive, elite networks proposed by others (Hirth 1998; Stoner and Nichols 2019). By the end of the Middle Formative (600–300 BC) we see change in the network graphs to more interconnected structures and less variance in richness indicative of wider availability to more settlements. These findings are consistent with expectations for market exchange, which has been argued to emerge when larger cities were being founded with populations who consumed goods they did not produce (Feinman *et al.* 1984; Winter 1984; see also Clayton 2021).

The marked differences in the network topology of the Late Postclassic compared to earlier periods is another finding that conforms to prior, less quantitatively weighted discussions of Late Postclassic Mesoamerican economic interaction. The Late Postclassic Mesoamerican world (e.g., Smith and Berdan 2000, 2003) has been described as commercialized, modularized, and yet with a high degree of overall connectivity. Although our focus has been on only one commodity (obsidian), the observation of relations in the graphs that dovetail with earlier findings serves as confirmation of the potential of social network analysis as an analytical tool.

Here, we have outlined a suite of axes of diversity and change for patterns of obsidian procurement and transfer in prehispanic Mesoamerica. The structure of connections linking different regions of Mesoamerica to one another shifted dramatically over time, moving obsidian through routes that only weakly conform with the geographical positioning of resources and instead reflect a combination of political, geographic, technological, and demographic factors that affected which sources were quarried and how far they were moved across the macroregion. We see that obsidian distributions in Mesoamerica exhibit cyclical patterning with macroscale cycles similar to those identified in other global contexts (e.g., Turchin and Hall 2003). We view these network trends as indications that the prehispanic Mesoamerican world was functionally interlinked so that even local perturbations had broader impacts.

The application of network analysis signifies a more explicit shift toward the examination of the relational properties of past social and economic systems (e.g., Kristiansen 2014; Terrell 2013). In this research, network analysis has enabled us to open a formal vantage into the structure of the prehispanic Mesoamerican economy, to reveal a highly dynamic, noncentralized system that does not conform to broadly held presumptions that such economies were static and localized. At the same time, the approach that we adopt opens new vantages and frames for the quantitative and formal examination of changes in integration, directionality of links, and the roles of individual settlements in a sequence of economic networks. Through these findings, we aim to generate and promote new ways of conceptualizing and dialoguing about prehispanic Mesoamerican economies and preindustrial economies more generally.

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Chapter 9

The Characterization of Small-Sized Obsidian Debitage Using P-XRF: A Case Study from Arequipa, Peru

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Abstract

The use of portable-XRF has allowed for greater ease of obsidian characterization worldwide, as the technique is relatively fast, inexpensive, and non-destructive. This has proven ideal for the analysis of obsidian artifacts within museum collections and archaeological field materials. Comprehensive analyses of large obsidian assemblages, including small-sized debitage, has increasingly identified rare, exotic obsidian sources not commonly found within archaeological contexts. However, due to the analytical limitations of pXRF, factors of specimen size, thickness, and surface irregularity create challenges for the accurate characterization of small obsidian fragments. In this chapter we report the efforts taken by The Field Museum's Elemental Analysis Facility in the characterization of obsidian artifacts from the Majes Valley of Arequipa, Peru dating to the Middle Horizon period (AD 600–1000). Approaches include direct comparison of artifact geochemical data to Andean geologic reference materials alongside several multivariate analyses to mitigate issues of specimen size. Our conclusions show the reliability of pXRF for the characterization of small obsidian debitage and its significance as it allowed us to reconstruct previously unknown caravan routes linking the Majes Valley to interior highland zones.

Introduction

The application of portable-XRF (pXRF) has allowed for wider accessibility and analysis of obsidian artifacts worldwide, as it is a rapid, non-destructive, and relatively inexpensive technique. This is especially true for Andean obsidian provenance studies conducted in museum and field settings over the last two decades (Bélisle *et al.* 2020; Craig *et al.* 2007; Giesso *et al.* 2020; Kellett *et al.* 2013; Matsumoto *et al.* 2018; Williams *et al.* 2012). Portable handheld XRF instruments allow the researcher to analyze an entire obsidian assemblage from formal tools down to small debitage (i.e. the waste product of lithic tool production). This is especially pertinent as restrictions on the export of lithic tools and/or their destruction during geochemical analysis is commonplace. However, various analytical limitations and challenges are present in the use of pXRF. These include issues of precision, or the "repeatability and stability of measurement" and accuracy, or how measurements conform to "correct" values (Hughes 1998: 108; see also Frahm 2013; Nazaroff *et al.* 2010; Speakman and Shackley 2013).

As a result of comprehensive analyses of total obsidian assemblages through pXRF, archaeologists have a greater likelihood of encountering small, rare obsidian sources not commonly identified that may only comprise < 1% of the overall artifact assemblage (e.g., Bélisle *et al.* 2020). Obsidian attributes related to material quality, abundance, and distance to the source are key factors in lithic production and the geologic

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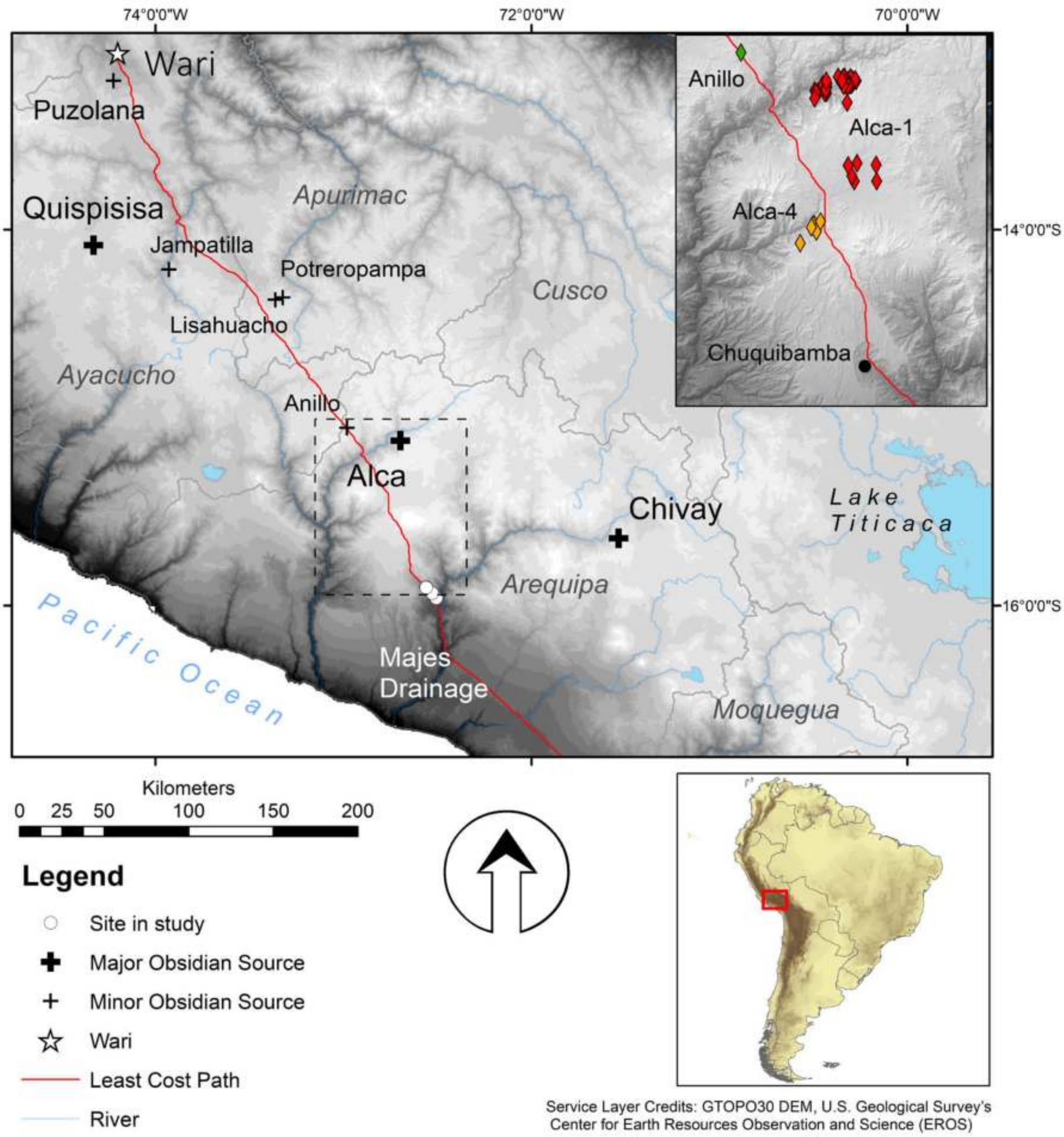

Figure 9.1. Base map of south-central Peru showing major and minor obsidian sources and the study region.

provenance of lithic types (Andrefsky 1994). Following Eerkens *et al.* (2007), the provenance of formal tools and small flake debitage, produced from periodic tool maintenance, may best indicate source diversity and transport distance.

Complete flaked stone tools are not always archaeologically deposited in the same area as their production or maintenance. Thus, debitage analyses are critical to reconstruct prehistoric lithic use and the entire operational chain from lithic source exploitation to finished tool (Andrefsky 2007; Sullivan and Rozen 1985). This makes the geochemical characterization of small obsidian flakes an ideal material to trace long-distance regional interactions and patterns of exchange, especially those related to tool curation and late-stage production. However, accurate pXRF analysis of small obsidian debitage is greatly impacted by issues of specimen size, thickness, and surface irregularity (Davis *et al.* 2011), making conclusive identifications of rare sources especially problematic.

In this chapter, we present results of a pXRF analysis of 303 obsidian artifacts recovered from four archaeological sites located in the Department of Arequipa in southern Peru. Nearly 80% of this assemblage corresponds to debitage including specimens that would normally be overlooked or left unanalyzed by pXRF due to their small size. Here we document the specific methodological approach taken to characterize these materials including multivariate analyses (following Glascock 1998 and Frahm 2016) and comparisons to Andean geologic obsidians analyzed with the same instrument and settings. Our results demonstrate the utility of pXRF in the accurate characterization of small-sized obsidian debitage and its broader significance to reconstructing prehistoric obsidian use and exchange. In comparison to formal tools, small-sized obsidian debitage show a greater diversity in geologic source and maximum distance from the study area. Using GIS cost-path analysis and regional studies of prehistoric roads, we also show how small-sized debitage allows us to reconstruct previously unknown caravan routes between Peru's montane valleys and interior highland zones.

Samples

Obsidian is a naturally occurring volcanic glass that was utilized by peoples worldwide to produce stone tools and decorative objects. In South America, obsidian occurs along the volcanic arc of the Nazca subduction zone of the central Andes and was utilized by prehistoric peoples beginning in the Terminal Pleistocene over 12,000 years ago (Rademaker *et al.* 2014; Sandweiss *et al.* 1998; Yataco and Nami 2016). Andean obsidian deposits vary in respect to glassiness; inclusions; size of nodules and pyroclasts; color(s) ranging from black, red, brown, green, and multicolored banded or mottled; and opacity (Glascock *et al.* 2007). Such attributes can vary greatly even within the same geologic source area (e.g., Rademaker *et al.* 2013, 2021). Although Andean obsidian sources cannot be distinguished solely based on macroscopic qualities, geochemical analyses have demonstrated that ratios of trace elements are unique to each obsidian source and can be used to characterize obsidian artifacts (Burger and Asaro 1977, 1979; Glascock *et al.* 2007). Artifact provenance studies show that three major geologic sources were predominantly exploited in the central Andes corresponding to Quispisisa, Alca, and Chivay obsidians (Figure 9.1). Over the last four decades, exploration of highland zones in the central Andes have identified and mapped these major obsidian deposits (Brooks *et al.* 1997; Burger *et al.* 1998a, 1998b; Burger and Glascock 2002; Jennings and Glascock 2002; Rademaker *et al.* 2013, 2021; Tripcevich 2007; Tripcevich and Contreras 2011).

Archaeological Context

This study examines a Middle Horizon (AD 600–1000) obsidian assemblage recovered from the upper Majes Valley in the department of Arequipa, Peru. During the Middle Horizon, obsidian was transported to its greatest extent across the Andes (Burger *et al.* 2000). This is in part due to the expansion of large-scale polities and states including the Wari empire, whose capital was located in Peru's highland Ayacucho Valley (Figure 9.1); and Tiwanaku, whose ceremonial capital was founded in the Titicaca Basin of Bolivia. At this time, residents of what is now the department of Arequipa adopted foreign styles, prestige items, and practices linked to such foreign groups. The emergence of inter-valley roads and caravan waystations at major confluences between Arequipa's coastal valleys provide evidence of the increasing scales of regional connectivity and economic exchange during the Middle Horizon (Cardona 2002; Jennings *et al.* 2015; Nigra *et al.* 2017; Tung 2012). As Arequipa was located at the crossroads of both Wari and Tiwanaku interests, provenance studies of obsidian allow us to investigate how local and exotic materials were utilized by communities located along coast-highland corridors.

In 2017, Reid (2020) conducted archaeological excavations at four Middle Horizon sites in the upper Majes Drainage and Chuquibamba Tributary under the auspices of the Proyecto Arqueológico Caminos Preincaicos Arequipa (PACPA). All four sites are located on the same prehistoric road artery that connects the Majes River Valley to the upper Chuquibamba drainage and adjacent highland zones (Figure 9.2). Two of these sites, Pakaytambo and El Tambo, correspond to an intrusive Wari occupation in the valley. Located at ~1700 masl, Pakaytambo is a small Wari enclave with orthogonal patio-groups organized around a monumental platform (35m × 60m) on top of which sits a D-shaped temple enclosure. Associated radiocarbon dates range from AD 770–990 (calibrated, SHCal20)[2] showing that this Wari temple center was first constructed in the latter half of the Middle Horizon during the apex of Wari expansionism.

El Tambo is an adjacent state center located under one km to the south that was built at the same time, if not earlier, than Pakaytambo. The site contains large bounding walls that enclose a large plaza (45m × 50m) and adjoining rectilinear compounds. Surface ceramics indicate that the site was repurposed by the Inka state who likely replicated Wari state strategies in the valley. Both the Wari and Inka took control of the natural chokepoint and transit route in the upper drainage between population centers in the Chuquibamba basin and those in the Majes Valley below.

Founded by local inhabitants of the Majes culture area, the waystations and ceremonial centers of Santa Rosa II (~1060 masl) and La Angostura (~1130 masl) are likely contemporaneous with the Wari occupation in

[2] All radiocarbon dates were calibrated using Hogg *et al.* 2020.

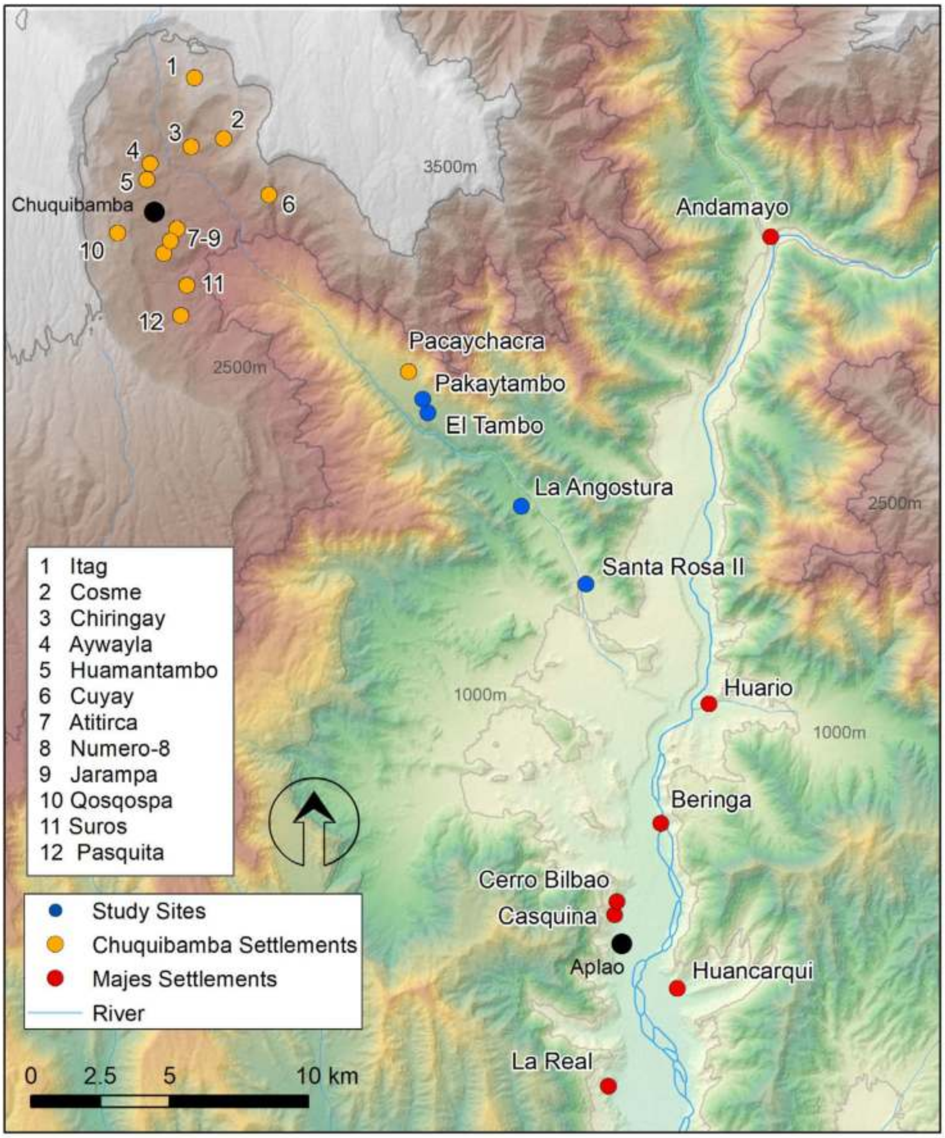

Figure 9.2. Map of study area with archaeological sites.

the upper valley. Santa Rosa II was first recorded by García and Bustamante (1990: 32–34) who noted the site's function as a caravan waystation at the drainage's major highland-coast confluence in the Majes. The site is organized around a large square plaza (67m × 67m) with an adjoining complex abutting the northern wall composed of rectilinear rooms and open patio spaces. This site layout is replicated in smaller form at La Angostura, only four kilometers away (Reid 2020). Both sites show local patterns of architecture, construction practices, and material culture that includes Wari-influenced ceramic forms and designs. In the surrounding vicinities of the formal plaza complexes, numerous corrals and the irregular stone footings of small structures are found, likely utilized by caravans and periodic residents. Materials also show long-distance connections including marine shell and petrified wood from the coast and obsidian from highland regions. Marking both sites are elaborate geoglyphs that include the forms of concentric circles, sun motifs, and other geometric designs, observable from nearby ridges and prehistoric trails.

The establishment of road and waystation infrastructure by local communities may have been one strategy of local elites to coopt an increase in caravan activity linked to the Wari state presence in Arequipa. As practices of ideology are embedded within exchange systems, Santa Rosa II and La Angostura also served as central places for large-scale gatherings perhaps linked to periodic festivals, barter fairs, and/or religious activities. At all sites, obsidian is abundant and present across most excavation units. Obsidian was mapped in-situ when observed during excavations and recovered through fine-screening of excavated sediments. The majority of obsidian specimens correspond to flaked stone tool debris and was recovered alongside other domestic refuse.

Obsidian Assemblage and Attributes

A total of 303 obsidian artifacts were analyzed in Peru by pXRF that complemented a formal lithic analysis of materials (Reid 2020). Complete obsidian tools include a core (n=1), preform (n=1), biface (n=1), scraper (n=1), blades (n=2), drills (n=3), projectile points (n=16), and biface/uniface fragments (n=36) that include the tips, medial sections, and bases of broken points (Table 9.1). Debitage large enough for pXRF analysis included complete and broken flakes (n=194) in addition to small bifacial thinning flakes (n=12) and shatter (n=36). This chapter focuses on these debitage materials, some of which show evidence of use wear likely related to expedient flake use.

Type	**Count (N)**
Biface	1
Projectile Point	16
Biface/Uniface Fragment	36
Blade	2
Core	1
Preform	1
Drill	3
Scraper	1
Flake	194
Bifacial thinning flake	12
Shatter	36
Total	303

Table 9.1. Number of obsidian artifacts characterized by pXRF by lithic type.

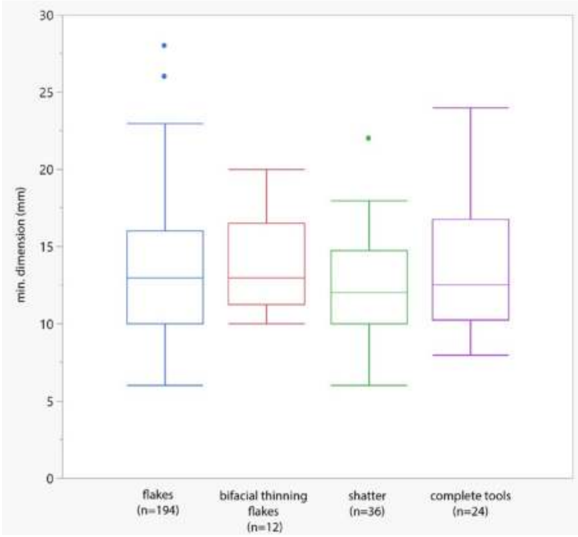

Figure 9.3. Size plots (minimum dimension of length or width) by artifact type analyzed by pXRF. Center line shows the mean with outlier indicated by individual points.

Specimen Size

Lithic artifact size is defined by several measurements including length, width, thickness, and weight. During the 2017 excavations, all soil was dry screened through fine mesh (1/16th inch or ~1.7mm), allowing for the recovery of micro-debitage measuring < 0.1g in weight. For flakes, length (mm) was measured as the straight-line distance perpendicular to the striking platform, otherwise from proximal to distal ends. Width (mm) and thickness (mm) were measured at their maximum dimensions. Weight (g) is also reported here as it is a key measurement related to the stage of lithic production. As a general practice, specimens that could fit over the instrument's aperture window were analyzed regardless of thickness or weight. Of the total obsidian assemblage recovered by the PACPA investigation, 65% was analyzed by pXRF. The remaining artifacts correspond to micro-debitage and were too small to fit over the instrument aperture.

Specimen size can greatly impact pXRF measurement accuracy if the sample does not fully cover the X-ray beam. For example, Liritzis (2008) shows systematic differences in ppm concentrations based on the percent coverage of the sample over the aperture window and uses this ratio to correct for size. In the current study, the aperture window of the instrument has a diameter of 10mm. As per Figure 9.3, only a handful of specimens did not completely cover the window. However, surface irregularities of debitage also impact X-ray beam coverage as not all specimens contain planar surfaces that can be placed flush with the aperture window. This was especially true for obsidian shatter.

Specimen Thickness

XRF analyses are also impacted by the thickness of a sample or specimen. This relates to the principle of "infinite thickness" or the sampling depth where all X-rays are absorbed and accurate readings are possible. Samples that are infinitely thick meet the critical point where increasing the thickness would not impact the measurement whether it be by 1mm or infinite mm. If X-ray penetration depth is greater than the thickness of the sample, the specimen cannot fully contain the X-ray beam or emit characteristic X-rays to accurately calculate an elemental quantity from a given (Frahm 2016: 450; Shackley 2011: 215). Various studies have attempted to determine the minimum thicknesses of obsidian samples needed for accurate source characterization. Infinite thickness differs per element. Davis *et al.* (2011: 61) observe that for mid-Z elements (Rb_{37} through Nb_{41} including elements of interest Rb, Sr, Y, Zr), minimum sample thickness ranges between 1.2 to 2.5mm. Other investigators suggest a cut-off at 2mm thickness (Shackley 2012).

Of the analyzed obsidian artifacts in this study, only a handful of flakes fall short of a 2mm thickness. By artifact type, lithic shatter tended to have greater thicknesses than flakes and complete tools (Figure 9.4). Specimens were placed over the aperture at their thickest points while also covering the entire beam window. However, it should be noted that only maximum thickness measurements were taken on artifact samples and thus do not account for the tapering thicknesses of most flakes, where the maximum thickness is associated with the bulb of force that forms below the striking platform. Various investigators have tested methods to correct for thin specimens such as the use of a small beam analyzer and normalization to the Compton peak (Ferguson 2012) or by taking the ratios between spectral peaks (Hughes 2010) and ppm concentrations (Frahm 2016).

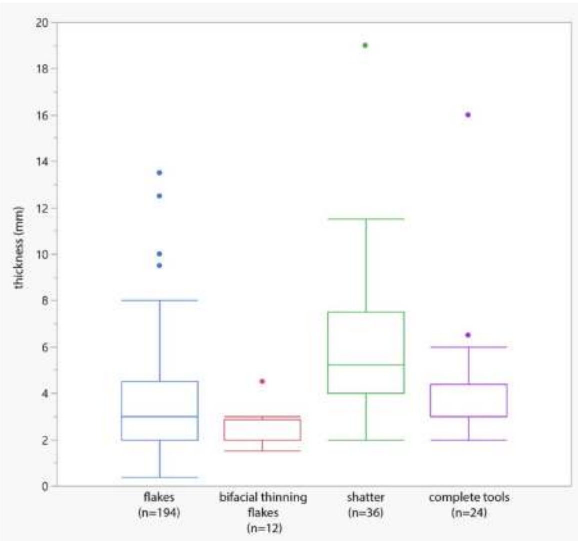

Figure 9.4. Thickness (mm) plots by artifact type analyzed by pXRF.

Specimen Weight

Weight is also a key measurement in lithic studies as it correlates to other linear dimensions and stage of lithic reduction (Shott 1994: 80). Of the analyzed obsidian artifacts, it is not surprising that the greatest weights are associated with complete tools followed by shatter, flakes, and then bifacial thinning flakes (Figure 9.5). Despite several outliers, the artifacts analyzed in this study are relatively small in size as reflected in minimum dimension, thickness, and weight. This is likely related to the precious nature of obsidian and distance from the source compared to more readily available local cherts and quartzes which show the greatest evidence of primary reduction at the study sites themselves (Reid 2020).

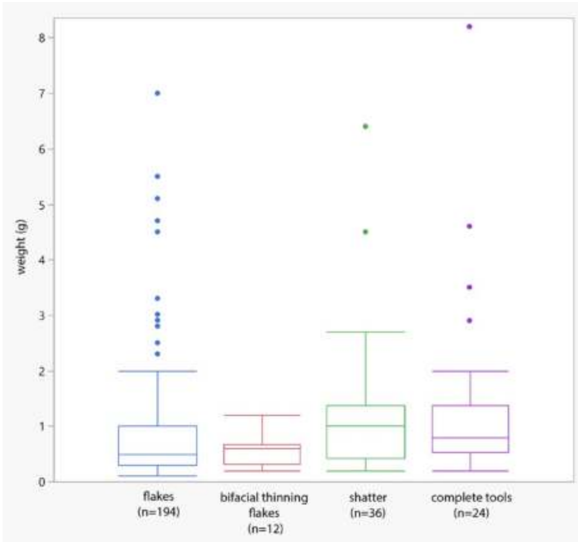

Figure 9.5. Weight (g) plots by artifact type analyzed by pXRF.

Methods

Analyses were conducted in Peru during the summers of 2017 and 2018 using a Thermo Scientific Niton XL3t Goldd+ portable X-ray Fluorescence (pXRF) instrument. The device is equipped with a 50kV silver anode tube with a Geometrically Optimized Large Area Drift Detector (GOLDD). Specimens were analyzed under "Test All Geo" mode using the settings of Main (40kV and 100μA), Low (25kV and 100μA), Light (15kV and 200μA), and High (50kV and 100μA) each set for 30 seconds for a total analysis run time of 120s per sample. Samples were subsequently analyzed using the instrument's "Soils" mode as it has been shown to provide more accurate results for concentrations of the element rubidium (Rb) above 150 parts-per-million (ppm). Filters under Soils mode were set on Main, Low, Light, and High for 30s each for a total run time of 120s. Samples were placed on the instrument aperture along their thickest and most planar surface to fully cover the X-ray beam detector field. Surfaces with cortex and evidence of devitrification were

Table 9.2. Relative standard deviation (RSD) over a two-year instrument operating period.

ID	n	Ti	Mn	Fe	Zn	Rb	Sr	Y	Zr	Nb	Ba	Pb	Th
CRB-2005	17	7.4	9.8	1.2	2.5	3.3	n.a.	3.5	3.5	2.9	n.a.	4	6.1
ELC-001	18	4.9	13.5	5.2	9.8	2.8	3.2	13.1	10.9	11.6	25.1	15.2	28.3

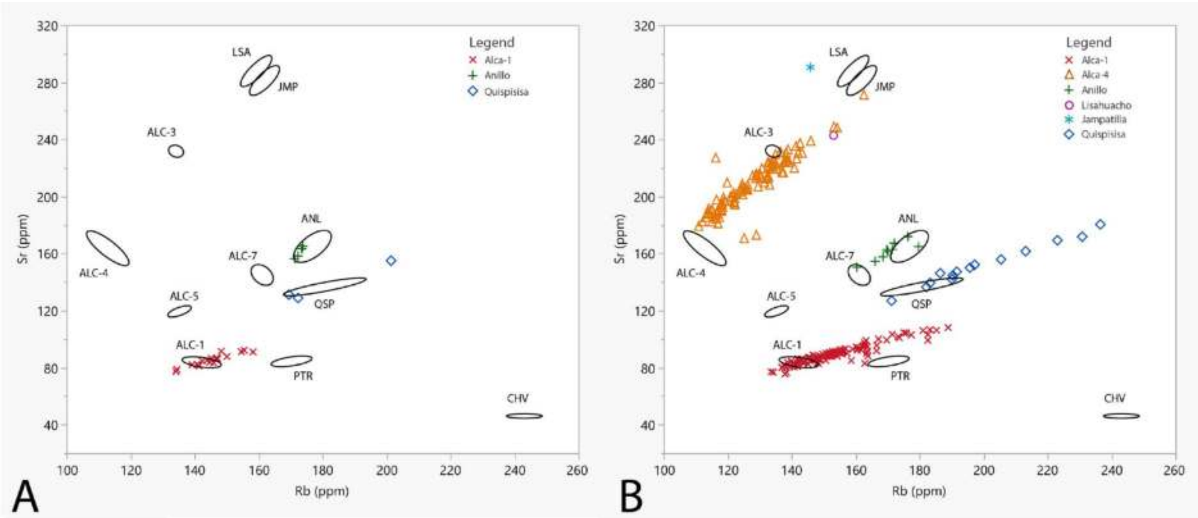

Figure 9.6. Bivariate plot of strontium (Sr) versus rubidium (Rb) concentrations measured by pXRF (ellipses drawn at 95% confidence around geologic source groups). A) Complete tools only; B) Debitage only.

avoided. Trace element data are reported in ppm for a total of 13 elements, including: potassium (K), calcium (Ca), titanium (Ti), manganese (Mn), iron (Fe), zinc (Zn), rubidium (Rb), strontium (Sr), yttrium (Y), zirconium (Zr), niobium (Nb), lead (Pb), and thorium (Th), however only a subset of these prove useful to discriminate Andean obsidians.

Collected data were then calibrated using a specialized correction developed by Mark Golitko (University of Notre Dame) using 21 in-house and certified standards including NIST 610, NIST 612, and Glass Buttes and Sierra Pachuca obsidians (see Glascock 1999). During field analyses, two obsidian standards were run at the beginning and end of each day to track instrument precision and variation over time. The two obsidian samples correspond to the Cedar Butte #2 source located in the Snake River Valley, Idaho (CRB2005) and El Chayal in Guatamala (ELC001). As indicated by the relative standard deviation (RSD), there was a high instrument precision/reproducibility (< 10% RSD) throughout the analysis especially for the elements of interest rubidium (Rb) and strontium (Sr) (< 3.3% RSD) (Table 9.2).

Despite data calibration using international standards, inter-instrumental comparisons of pXRF data can prove problematic, making source assignments to previously published elemental values unreliable (Frahm 2013; Shackley 2010; Speakman and Shackley 2013). To assign artifacts to their respective character groups (related to known or unknown geologic sources), we followed a rigorous statistical approach following Glascock *et al.* (1998). In addition, geologic samples collected from central Andean obsidian sources were measured on the Niton XL3t Goldd+ pXRF under the same instrumental settings. Geologic obsidians were loaned or donated to the Field Museum's Elemental Analysis Facility by Kurt Rademaker, Nicholas Tripcevich, and Michael Glascock for use in this study. After the calibration of raw artifact and geologic data, ppm values were log10 transformed for statistical analyses using the software JMP Pro v15.2.0.

Results

Obsidian Group Characterization: Multivariate Analyses

Here we present the elemental ppm concentrations of the analyzed obsidian artifacts from the upper Majes Valley and Chuquibamba Tributary. Due to the overall small size of the measured artifacts, elemental concentrations are likely over-estimated for small specimens. This may initially seem counter-intuitive, as when a sample is too small to fully cover the aperture or does not meet the infinite thickness for an element of interest, one might expect a relative deficit in X-rays bombarding the sample that would result in lower elemental intensities. However, our findings mirror those of Frahm (2016: 451), who also utilized a Niton XL3t Goldd+ analyzer and found that trace element concentrations tend to *increase* as specimen size *decreases* for samples measured with only air surrounding them. This is likely due to an underestimation of mass for small samples within the internal fundamental parameter (FP) algorithm used to calculate the ppm concentrations under the “Test-all Geo” mode.

Prior analyses using the Niton XL3t Goldd+ have shown that for samples with concentrations of Rb higher than 150ppm, “Soils” mode is ideal. In this mode, the internal software of the instrument uses the Compton peak for the determination of mass/volume normalization. For small specimens, a smaller fraction of the higher energy X-rays will interact with the sample (i.e., volume or mass) exposed to the beam. But the lower energy X-rays which have a shorter range are more likely to interact and return a signal to the detector. Since the instrument’s software uses the Compton peak (higher energy X-rays) for the mass/volume normalization, this explains why lower Z elements (Fe, Zn, Rb) are more inflated than higher Z elements (Zr). The overestimation of Rb concentrations under “Soils” mode can prove problematic as this element (alongside Sr) is most commonly used to distinguish Andean obsidians using pXRF (Glascock *et al.* 2007).

The relationship between size and an overestimation of ppm elemental concentrations within the Majes obsidian materials is clearly identified when comparing debitage versus complete obsidian tools. A scatterplot of Sr versus Rb ppm concentrations for complete obsidian tools fall within or close to geologic ellipses produced from measurements of geologic samples analyzed using the same Niton XL3t Goldd+ instrumentation and settings (Figure 9.6A). However, for small-sized debitage, character groups display long tails at their extremes due to the overestimation of ppm values for Rb (Figure 9.6B). Complicating the picture, several assigned character groups overlap with more than one geologic source when considering only Sr versus Rb concentrations. Consequently, we cannot rely on the traditional Sr versus Rb scatterplot alone for geochemical group characterization of the Majes obsidian materials. This necessitated a more robust approach using several multivariate analyses to accurately characterize small-sized obsidian debitage.

Initial artifact character groups were created based on a Ward’s hierarchical cluster analysis using the

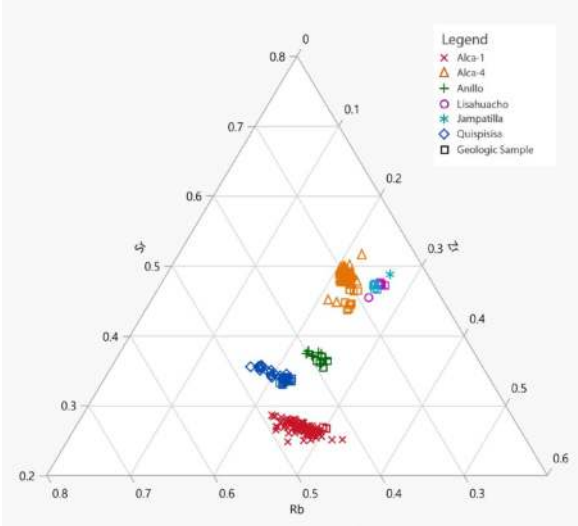

Figure 9.7. Ternary plot of strontium (Sr), rubidium (Rb), and zirconium (Zr) for obsidian debitage.

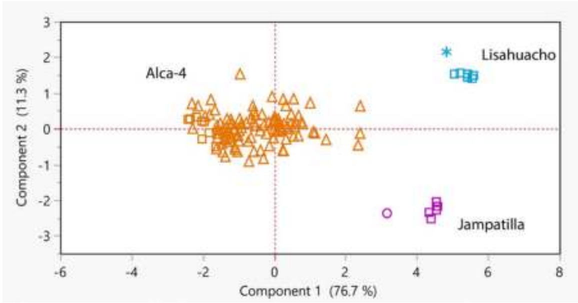

Figure 9.8. Principal component analysis (PCA) of elements Rb, Sr, Y, Zr, and Th.

elements Sr, Rb, and Zr. These groups were then interrogated using various methods. One alternative to bivariate scatterplot visualizations is the use of ternary plots, or three-axis plots, where ppm concentrations are converted into proportions for each sample. Here a ternary plot between Sr, Rb, and Zr more clearly defines the character groups of the Majes debitage materials (Figure 9.7). Multivariate analyses have also been shown to reduce the skewing effects of sample size. For example in principal component analysis (PCA), multiple elemental concentrations can be reduced to their underlying covariances typically inspected through the first two principal components (Glascock *et al.* 1998). As an initial step, PCA is useful for identifying discriminating elements of interest for further multivariate comparisons. Here we present the results of a PCA using logged elemental ppm concentrations of Rb, Sr, Y, Zr, and Th which distinguishes the obsidian groups Alca-4, Lisahuacho, and Jampatilla (Figure 9.8).

Previous investigations have illustrated the use of elemental ratios of ppm concentrations (Frahm 2016)

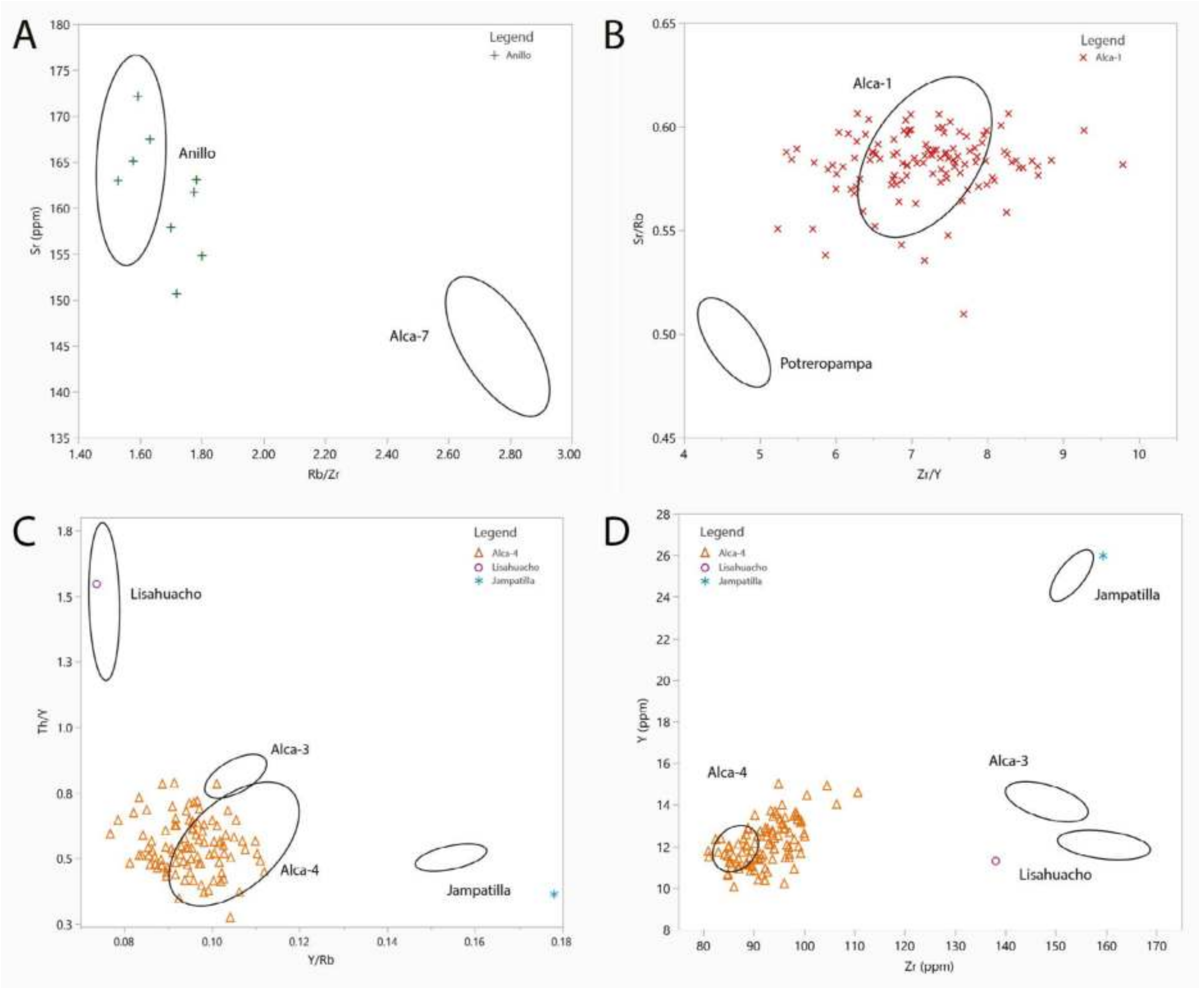

Figure 9.9. Bivariate plots of obsidian debitage element concentrations measured by pXRF (ellipses drawn at 95% confidence around geologic source groups). A) Anillo versus Alca-7 using Sr and ratio Rb/Zr; B) Alca-1 versus Potreropampa using ratio Sr/Rb versus Zr/Y; C) Alca-4 versus Alca-3, Lisahuacho, and Jampatilla using ratio Th/Y and Y/Rb; and D) Y versus Zr.

and peak intensities (Hughes 2010) in the analysis of small-sized obsidian debitage. The underlying premise is that if artifact size systematically impacts all mid-Z trace elements, then converting ppm concentrations or spectral peak values into elemental ratios will mitigate any disproportional skewing. Most notably, Frahm (2016) illustrates how very small obsidian fragments can be accurately sourced in a reexamination of historic pXRF and energy-dispersive (ED)-XRF datasets as well as experimental materials of varying size. For one obsidian group, Frahm (2016: 458) was able to reduce the relative standard deviation (RSD) corresponding to Sr from 14% down to 3–4% when ratioing Sr concentrations with Rb, Nb, and Zr.

Due to the proximity of some Andean geologic groups when comparing only Sr versus Rb, we can use the ratios between various elements of interest to aid in group characterization. Ratios of Rb/Zr versus Sr best distinguishes Anillo from Alca-7 (Figure 9.9A), and Sr/Rb versus Zr/Y further distinguishes Alca-1 from Potreropampa (Figure 9.9B). Ratios also confirmed the presence of Lisahuacho and Jampatilla obsidian within the assemblage (Figure 9.9C-D). Both artifacts pertain to small flakes and represent the first evidence of these sources in the department of Arequipa. Discriminant analysis was also used in tandem with multivariate analyses to test these character groups (Figure 9.10).

Character Group Assignment

Our results indicate the presence of six discrete geologic obsidian sources utilized by occupants of the upper Majes Valley and Chuquibamba Tributary during the Middle Horizon. These correspond to the local Arequipa obsidian groups Alca-1, Alca-4, and Anillo as

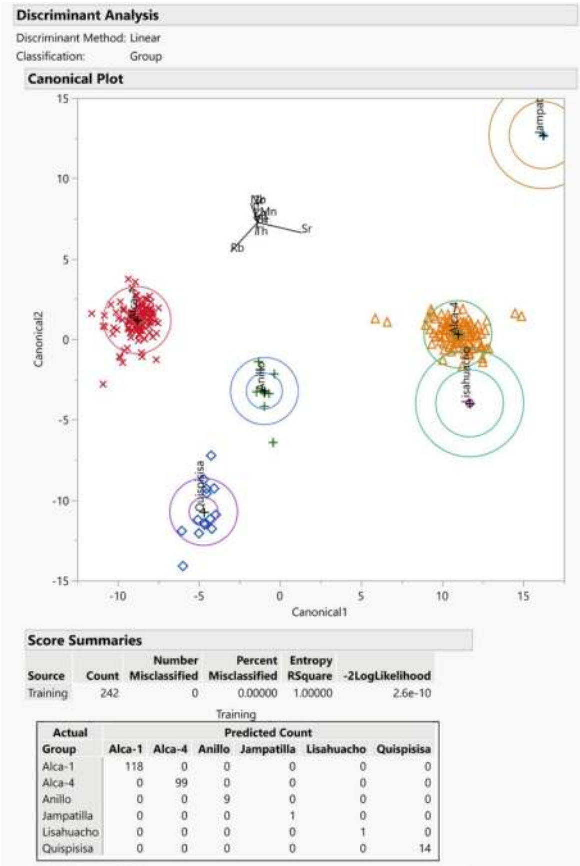

Figure 9.10. Results of discriminant analysis using the elements: Ti, Mn, Fe, Zn, Rb, Sr, Y, Zr, Nb, and Th.

well as exotic obsidians including Quispisisa, Jampatilla, and Lisahuacho from the south-central highlands of Ayacucho and Apurímac (Figure 9.1). In this chapter we present both the count (Table 9.3) and weight (Table 9.4) of analyzed specimens. This is an important practice as reporting only counts can over-emphasize the presence of an obsidian source. Hypothetically, by count, ten small retouch flakes of Source A outnumber one large biface of Source B, however by weight the reverse may be true. Following regional trends, Alca-1 is the predominant obsidian comprising nearly half of analyzed debitage by count and weight. This is followed closely by Alca-4 (41%), whereas small amounts of Anillo (7%) and Quispisisa (3%) were also detected. Lisahuacho and Jampatilla represent < 1% of the assemblage by count and weight represented by a single flake from each source.

Discussion

The use of pXRF instrumentation in the field allows investigators to analyze entire obsidian assemblages in a relatively rapid, inexpensive, and non-destructive manner. For this study, specimens that could fit over the X-ray beam aperture (10mm diameter) of the Niton XL3t Goldd+ pXRF were measured. Variation in specimen size, thickness, and surface irregularity did impact the accuracy of pXRF results for small-sized debitage where ppm concentrations are likely overestimated. However, following prior studies (e.g., Frahm 2016), the use of multivariate analyses and the ratioing of elemental concentrations allowed for accurate obsidian source characterization in direct comparison to geologic materials. Following these results, future studies may attempt to further push size limits to include microdebitage. For example, in this case study, microdebitage corresponded to roughly one third of the archaeological obsidian assemblage however these specimens were not analyzed. Especially difficult specimens to characterize could then be targeted for export for analysis by traditional XRF, INAA, or LA-ICP-MS (e.g., Kellett *et al.* 2013).

The use of pXRF allows for wider detection of rare and exotic obsidian sources that may only comprise < 1% of the total assemblage. During the Middle Horizon, there

Table 9.3. Geologic source characterization of obsidian debitage by count (N).

Type by count (N)	Alca-1	Alca-4	Anillo	Lisahuacho	Jampatilla	Quispisisa	Total
Flake	97 (47.1%)	85 (41.3%)	9 (4.4%)	1 (0.5%)	1 (0.5%)	13 (6.3%)	206 (85.1%)
Shatter	21 (58.3%)	14 (38.9%)	0	0	0	1 (2.8%)	36 (14.9%)
Total	118 (48.8%)	99 (40.9%)	9 (3.7%)	1 (0.4%)	1 (0.4%)	14 (5.8%)	242 (100%)

Table 9.4. Geologic source characterization of obsidian debitage by weight (g).

Type by weight (g)	Alca-1	Alca-4	Anillo	Lisahuacho	Jampatilla	Quispisisa	Total
Flake	79.6 (48.0%)	63.2 (38.1%)	15.3 (9.2%)	0.3 (0.2%)	0.9 (0.5%)	6.6 (4.0%)	165.9 (79.1%)
Shatter	20.3 (46.2%)	23.4 (53.3%)	0	0	0	0.2 (0.5%)	43.9 (20.9%)
Total	99.9 (47.6%)	86.6 (41.3%)	15.3 (7.3%)	0.3 (0.1%)	0.9 (0.4%)	6.8 (3.2%)	209.8 (100%)

is strong evidence that obsidian bifaces and projectile points were transported and exchanged over great distances in completed form where initial production occurred off-site (Bencic 2000; Burger *et al.* 2000). Since formal tools are not always deposited at the place of their production, often only the smallest retouch flakes related to periodic maintenance and sharpening of a tool's edge may be archaeologically recovered. In this case study, this is exemplified by the presence of a single bifacial thinning flake composed of Lisahuacho obsidian. It is therefore critical that studies include small obsidian debitage within geochemical provenance studies in order to best detect the diversity of obsidian usage in the past (e.g., Eerkens *et al.* 2007).

PXRF analysis of obsidian debitage from the upper Majes Drainage provides greater insight into prehistoric regional economies and long-distance interactions related to the broader social transformations of the Andean Middle Horizon. The use of the local obsidians Alca-1, Alca-4, and Anillo show a well-integrated highland-montane valley network in the proximate region, whereas the presence of Quispisisa, Jampatilla, and Lisahuacho provide evidence of long-distance interaction with the south-central highlands of Peru. The heterogeneity of the Alca source region (Rademaker *et al.* 2013, 2021) also allows us to pin-point the locations of obsidian extraction on the local landscape. From the rim of the Chuquibamba basin, Alca-4 is the nearest high quality bedrock source accounting for its near equal presence alongside Alca-1 in total analyzed artifacts in this analysis (Figure 9.1). This study is also one of the first investigations to detect the prehistoric use of Anillo obsidian. The Anillo source is located on the western side of the Cotahuasi Valley in close proximity to a major caravan route that links Arequipa to Apurímac and Ayacucho (Tripcevich 2016).

Minor amounts of Quispisisa obsidian are also present in the upper Majes Valley at the study sites Santa Rosa II and La Angostura. At other settlements in Arequipa and Moquegua, Quispisisa comprises ~10–20% of sourced obsidian assemblages (Glascock 2012; Rizzuto and Jennings 2021; Tung 2012; Williams *et al.* 2010, 2012). Quispisisa is commonly associated with Wari exchange networks as it was the preferred obsidian source of the Wari state (Burger *et al.* 2000). Analysis of small-sized obsidian debitage further allowed for the characterization of the exotic sources Jampatilla and Lisahuacho originating in the departments of Ayacucho and Apurímac respectively. These sources are found enroute from the Wari heartland to the Majes Drainage, and this study is the first to detect their presence in Arequipa. In consideration of lithic tool type, 72.7% of exotic non-Arequipa obsidians analyzed in this study are debitage, the majority of which correspond to late-stage production or maintenance. For example, the only specimen assigned to Lisahuacho is a small bifacial thinning flake, suggesting exotic obsidians were transported into the region as already completed tools or near-finished products, perhaps as trade items.

Obsidian is only one material good among many that would have been transported across caravan routes between highland and coastal zones. The minor presence of exotic obsidians, including single objective flakes, can be interpreted as one-off or random finds; however, they can play a critical role in reconstructing down-the-line exchange networks and serve as proxies to reconstruct broader social networks (e.g. Golitko *et al.* 2012). Obsidian provenance data, alongside other lines of material evidence such as prehistoric roads, suggest that a Middle Horizon caravan route once linked Wari Ayacucho to far southern Peru, likely connected by various waystation sites such as Santa Rosa II and La Angostura. This route would have extended from Ayacucho into Apurímac with travel southward, crossing the Cotahuasi Valley near the Anillo obsidian source, and entering the upper Majes Drainage near Chuquibamba.

Caravan activity was facilitated by both local populations in the Majes Drainage and an intrusive Wari state. State enclaves at the sites Pakaytambo and El Tambo were established at the natural chokepoint in the valley to perhaps control this major travel route. Obsidians local to Arequipa also flowed in the opposite direction, including small amounts of Alca-1 identified at the Wari administrative center Jincamocco, the Wari capital, and Espíritu Pampa on the eastern Andean slopes (Burger *et al.* 2000; Fonseca and Bauer 2020; Kaplan 2018; Schreiber 1992). The obsidian data support initial models of Wari travel routes in southern Peru (Williams 2009) and the survey of Middle Horizon roads in Arequipa (Cardona 2002).

Conclusion

This study demonstrates the reliability of pXRF for the analysis of small sized obsidian debitage. Various multivariate methods are suggested to mitigate factors of debitage size, thickness, and surface irregularity that negatively impact measurement accuracy. These include hierarchical cluster analysis, ternary graphing, principal component analysis, ratioing elemental ppm concentrations, and discriminant analysis in direct comparison to representative geologic samples. Our results indicate an accurate characterization of Andean obsidian artifacts with minimum dimensions as small as 0.6mm in size, 0.5mm thickness, and 0.1g in weight.

The characterization of rare and exotic obsidian sources that comprise < 1% of the overall artifact assemblage highlights the importance of including small debitage within geochemical analyses. Obsidian was often exchanged and transported as completed tools and bifaces. Various archaeological processes may result in the final use or discard of such tools off-site at the end of their operational lifetime. Thus, small flaked debitage related to periodic tool maintenance may best indicate the range and presence of exotic obsidians. In this case study, such small sized debitage allows us to elucidate the provisioning of obsidian materials from both local and intrusive state contexts. The sourcing of obsidian artifacts from road waystations also highlights the role of long-distance llama caravans in the movement of this precious material from highland sources to the coastal valleys of the Andes during the Middle Horizon period.

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Appendix 9.1

Obsidian artifact and geologic specimen description and parts per million (ppm) elemental concentrations.
See supplementary data for this appendix online: https://doi.org/10.32028/9781803273600-online.

SAMPLE	Group	Type	weight (g)	length (mm)	width (mm)	thickness (mm)	Cortex present/ absent	K	Ca	Ti	Mn	Fe	Zn	Rb	Sr	Y	Zr	Nb	Ba	Pb	Th	U
01-00-0005	Alca-1	flake	1.4	17	23	3.5	0	37072.1	3918	753	277	5732	41.8	162.9	83.0	11.5	88.6	9.4	515.5	17.8	9.6	4.5
01-00-0007	Alca-1	flake	0.1	15	8	1	0	52470.8	3883	1094	304	6751	59.6	175.8	104.2	14.1	88.3	19.1		24.9	11.9	
01-00-0011c	Alca-1	flake	0.7	22	7	5	0	41904.4	3267	823	273	5993	43.1	151.9	88.2	12.8	96.8	11.6	328.1	17.9	10.8	4.0
01-00-0015	Alca-1	flake	0.4	13	18	3.5	0	42856.4	5269	870	228	6066	42.6	152.5	88.3	13.1	77.2	13.7		24.1	10.2	5.4
01-00-0018d	Alca-1	flake	1	20	16	4	0	38483.9	4308	760	295	5840	42.4	147.9	85.9	13.3	92.2	10.3	412.9	17.2	10.0	3.6
01-00-0019b	Alca-1	flake	1	15	14	4	0	38122.5	3923	761	289	5791	42.7	142.8	85.6	12.3	91.2	9.8	399.9	19.9	10.3	3.3
01-00-0021a	Alca-1	flake	1.4	15	25	5	0	37285.9	3858	756	269	5767	42.8	140.9	82.1	11.6	91.2	10.4	446.1	16.2	9.8	3.3
01-00-0021d	Alca-1	flake	0.3	13	16	2.5	0	46929.0	3749	909	218	6347	47.6	163.2	95.6	13.9	99.9	13.7		20.6	11.5	
01-00-0022a	Alca-1	flake	0.4	11	12	2.5	0	42548.7	4111	852	241	6075	40.5	155.3	91.5	12.7	96.1	12.4	224.8	17.2	11.2	
01-00-0031	Alca-1	flake	1	14	17	5.6	0	36965.0	5366	864	369	5697	40.0	138.1	80.2	12.0	73.1	11.2	332.9	22.5	8.5	4.7
01-00-0032a	Alca-1	flake	0.4	22	10	3	0	44469.2	3978	864	235	6205	43.1	156.0	92.4	12.6	100.1	12.5	238.7	18.6	12.1	4.8
01-00-0033a	Alca-1	flake	1.6	25	20	4.5	0	39041.6	3986	784	265	5835	41.2	145.3	85.9	12.7	91.2	11.3	359.5	19.2	11.2	
01-00-0033b	Alca-1	flake	1.5	19	32	4.5	0	38426.9	3942	769	278	5817	42.9	147.0	85.5	11.9	91.7	10.5	413.2	18.6	8.9	3.9
01-00-0034a	Alca-1	flake	0.5	13	18	3	0	41083.9	5215	833	247	5872	39.4	147.6	84.8	13.1	82.9	12.3	275.4	23.0	10.8	3.2
01-00-0036a	Alca-1	flake	2	18	21	6	0	36909.1	4555	789	241	5569	44.5	138.4	76.4	12.0	78.3	10.9	395.9	21.7	9.4	3.3
01-00-0036b	Alca-1	flake	1.5	32	18	4	0	38086.0	4519	841	211	5680	45.4	138.7	83.7	12.0	77.5	12.4	281.3	19.6	11.6	5.9
01-00-0036c	Alca-1	flake	1.6	26	18	3	0	35165.8	4902	719	279	5674	46.7	137.7	82.1	12.6	77.9	10.7	428.8	24.8	11.8	2.9
01-00-0036d	Alca-1	flake	1.2	23	16	3	0	38828.2	5185	822	226	5717	45.5	142.0	86.1	12.5	78.6	12.2	269.2	22.9	11.1	3.5
01-00-0036f	Alca-1	flake	1.3	17	16	6	0	35896.5	4330	776	287	5584	41.5	134.3	76.7	12.7	79.6	10.7	387.1	20.6	9.1	
01-00-0036g	Alca-1	flake	0.8	17	18	3.5	0	40340.9	5180	836	219	5909	40.6	148.0	83.3	11.2	78.9	13.0	299.9	24.4	10.8	4.6
01-00-0036i	Alca-1	flake	0.2	20	20	2	0	40121.5	5057	895	249	6023	42.0	146.7	88.9	11.8	87.3	12.8	249.7	23.2	10.5	5.3
01-00-0036j	Alca-1	flake	0.7	16	19	2	0	42018.6	5075	895	224	6001	45.5	152.6	89.6	12.3	80.0	14.4	232.6	21.9	9.7	5.3
01-00-0040	Alca-1	flake	0.5	9	15	5	0	37295.5	5033	835	265	5571	38.6	139.4	80.4	13.0	78.0	10.7	367.4	22.1	10.5	5.1
01-00-0041	Alca-1	flake	0.5	13	11	4	1	41222.7	5729	893	267	5925	44.1	148.9	86.5	13.1	78.2	12.6	342.8	21.0	12.2	4.8
01-00-0045	Alca-1	flake	0.5	12	13	3.5	0	38536.4	5339	835	256	5760	49.3	144.0	83.9	13.4	76.5	11.2	378.9	22.0	10.1	6.2
01-00-0055b	Alca-1	flake	0.9	15	18	3	0	37043.1	5851	778	240	5574	31.4	163.5	90.0	15.3	80.0	12.9	146.7	23.1	13.6	8.1
01-00-0060d	Alca-1	flake	0.4	15	15	2	0	44610.0	4369	915	234	6238	42.7	163.6	94.3	12.0	104.4	12.7		19.8	11.2	
01-00-0066	Alca-1	flake	0.7	18	15	3	0	38398.5	5191	812	226	5741	43.8	140.8	80.5	11.6	78.2	13.2	322.8	19.6	10.6	4.9
01-00-0071	Alca-1	flake	0.8	17	14	3.5	0	37565.7	5173	852	262	5714	39.7	139.8	84.3	11.9	82.3	11.8	297.3	20.2	11.1	5.2
01-00-0071b	Alca-1	flake	0.2	8	13	4	0	38876.2	4790	844	192	5782	39.1	141.0	82.9	11.9	77.1	12.8	260.1	22.6	10.3	4.7
01-00-0073a	Alca-1	flake	0.3	14	12	2.5	0	40407.5	5889	823	287	5832	42.0	145.2	86.8	11.7	80.8	13.1	327.7	21.7	9.2	4.1
01-00-0073d	Alca-1	flake	0.7	12	12	5.5	0	61493.4	4961	1264	368	7547	63.4	188.9	108.1	13.9	94.7	20.9		29.8	14.1	4.6
01-00-0075c	Alca-1	flake	1	21	15	3	0	41323.9	4182	803	258	5955	42.0	154.8	90.8	11.5	95.1	12.3	223.5	15.6	8.1	
01-00-0075d	Alca-1	flake	4.5	26	35	6	0	43387.2	4309	824	223	6227	40.5	162.2	95.1	12.8	95.4	12.2		17.4	9.9	

SAMPLE	Group	Type	weight (g)	length (mm)	width (mm)	thickness (mm)	Cortex present/ absent	K	Ca	Ti	Mn	Fe	Zn	Rb	Sr	Y	Zr	Nb	Ba	Pb	Th	U
01-00-0080a	Alca-1	flake	0.4	11	16	2	0	42377.4	5092	907	246	6022	43.2	151.8	90.5	12.3	85.3	15.0		22.6	12.2	4.1
01-00-0080b	Alca-1	flake	0.2	19	10	2	0	42455.3	5526	870	161	5943	40.2	153.0	89.7	11.5	83.9	14.0		20.4	9.7	4.1
01-00-0120	Alca-1	flake	0.4	16	10	2	0	42695.4	5159	886	197	6053	45.7	154.3	87.9	13.4	80.4	14.2		19.9	10.9	3.3
01-06-0001	Alca-1	flake	0.2	14	10	12.5	0	41932.7	2909	795	158	5717	40.2	147.5	86.8	12.5	90.5	11.5		15.5	8.4	
01-06-0006	Alca-1	flake	0.7	21	15	2	0	43448.3	4079	868	240	6073	43.3	156.8	93.3	13.2	101.7	11.9		16.9	9.8	
02-00-0028c	Alca-1	flake	0.4	20	17	2	0	41356.4	4099	774	246	5832	41.7	158.7	84.9	13.4	96.1	11.8	399.3	20.7	8.0	
02-00-0034d	Alca-1	flake	0.4	18	13	2	0	37673.3	3517	759	264	5716	44.7	142.0	80.8	11.7	90.9	9.6	396.4	16.8	11.7	
02-00-0037e	Alca-1	flake	0.3	10	15	1.5	0	53706.9	4029	1054	268	6963	50.7	181.1	105.9	14.9	104.8	17.6		20.1	14.3	
03-00-0001b	Alca-1	flake	1.3	17	18	8	0	40631.8	4602	773	315	6061	46.5	155.7	89.5	12.6	94.4	11.4	529.8	18.9	13.4	
03-00-0002	Alca-1	flake	0.6	16	18	3	0	40684.8	3964	796	205	5948	45.6	150.7	90.1	13.2	92.2	11.7	246.4	17.5	9.1	
03-00-0003a	Alca-1	flake	1.2	17	15	5	0	41554.5	4623	799	247	6089	42.9	153.4	89.9	13.6	92.2	12.3	240.1	19.6	10.1	
03-00-0003b	Alca-1	flake	0.3	10	12	3.5	0	36541.7	3954	730	294	5674	41.1	142.4	83.7	12.4	66.3	9.8	559.9	16.3	12.6	
03-00-0005	Alca-1	flake	0.4	12	11	4	0	39196.5	3939	782	247	5776	45.2	149.9	87.5	11.3	95.1	10.3	359.7	17.5	10.8	
03-00-0007	Alca-1	flake	1.2	16	13	7	0	36846.0	3934	708	266	5642	40.4	141.9	85.9	11.9	83.1	10.5	539.4	17.0	11.5	
03-00-0008	Alca-1	flake	0.6	12	14	4.5	0	38208.6	3796	750	233	5775	43.0	143.2	86.0	11.7	96.1	9.9	311.7	17.6	9.4	
03-00-0011c	Alca-1	flake	1.3	11	21	8	0	36188.9	4022	768	336	5677	46.9	143.8	82.9	13.4	90.8	8.2	1016.0	17.5	11.5	
03-00-0013a	Alca-1	flake	1.5	18	22	6	0	41186.7	4764	756	317	5931	44.3	153.5	90.8	15.2	99.7	10.7	443.9	17.3	12.2	
03-00-0013b	Alca-1	flake	0.1	10	7	2	0	41586.7	4368	798	258	5952	44.3	151.9	89.4	12.9	93.8	11.6	292.0	18.2	10.4	
03-00-0015	Alca-1	flake	1	15	19	6	0	38617.8	4365	750	268	5871	45.5	147.3	88.1	12.4	115.3	10.5	461.3	18.1	12.8	
03-01-0012	Alca-1	flake	0.4	13	17	2.5	0	44221.6	5277	892	269	6220	45.4	162.6	95.5	13.0	96.7	12.7		18.5	10.4	
03-04-0004a	Alca-1	flake	0.8	13	23	3	0	52694.9	4993	822	227	5998	43.1	151.3	88.2	12.1	100.8	11.8	261.0	20.4	8.5	
03-04-0004b	Alca-1	flake	0.7	17	17	3	0	57822.4	9279	801	234	6015	41.8	152.8	88.7	13.2	111.7	11.3	279.6	17.1	9.7	
03-04-0008a	Alca-1	flake	0.4	12	20	2.5	0	39450.7	3925	750	289	5935	45.2	151.7	88.4	13.2	94.2	11.5	405.5	20.1	10.5	
03-04-0008b	Alca-1	flake	0.9	24	6	5.5	0	41223.8	5555	814	223	5832	40.1	148.2	86.5	13.0	84.2	11.6	297.3	20.6	10.7	3.4
03-04-0009	Alca-1	flake	0.3	13	25	1	0	56422.9	35593	805	225	6538	43.1	173.7	100.9	12.5	108.5	15.2		19.2	12.2	
03-04-0010	Alca-1	flake	0.8	8	9	5.5	0	43527.2	6061	804	349	6243	41.6	160.2	94.4	13.9	76.6	12.1	484.9	25.3	13.8	4.0
03-04-0013	Alca-1	flake	1.3	12	15	6.5	0	34564.3	40850	931	339	6112	47.7	153.8	91.3	13.5	91.3	10.8	515.1	17.1	11.6	3.1
03-04-0016	Alca-1	flake	0.2	12	10	3	0	44459.3	4577	799	193	6094	42.5	161.7	92.4	12.4	97.5	11.3	260.5	21.0	10.0	
03-04-0020	Alca-1	flake	0.4	15	16	2.5	0	45152.7	5899	870	279	6367	46.7	166.6	95.6	14.3	98.0	12.7		22.6	12.0	
03-04-0022	Alca-1	flake	1.1	20	13	6	0	39160.5	7625	902	305	5973	47.3	148.8	86.2	12.7	94.0	10.4	472.7	16.6	12.4	
03-05-0002	Alca-1	flake	0.4	17	10	3	0	42798.5	4464	837	211	6114	44.2	159.1	92.8	12.3	106.1	12.2	241.0	18.9	10.4	
03-05-0005	Alca-1	flake	0.4	11	15	2.5	0	40610.7	11880	791	172	6067	41.6	155.6	91.0	12.8	94.7	12.1	203.5	17.3	10.5	
03-07-0007	Alca-1	flake	0.3	13	11	2.5	0	50775.8	6367	994	383	7113	55.3	183.3	106.6	11.8	116.0	14.4	287.2	20.6	12.5	
03-07-0010	Alca-1	flake	0.2	9	14	2	0	45668.7	4192	849	237	6198	46.1	163.3	99.0	12.5	103.3	14.3		17.6	11.2	
03-07-0013	Alca-1	flake	0.2	15	9	2	0	51511.1	15007	800	281	7034	54.8	185.3	106.2	14.0	103.1	15.2		19.6	11.3	
03-07-0020	Alca-1	flake	1.2	16	14	5.5	0	41587.3	4475	776	284	5866	42.8	149.2	87.8	12.0	93.4	10.4	400.4	18.2	10.0	
03-07-0021	Alca-1	flake	0.6	14	13	5	0	35745.7	4540	804	263	5750	45.2	142.0	83.1	12.0	91.4	9.3	462.3	18.4	7.7	

SAMPLE	Group	Type	weight (g)	length (mm)	width (mm)	thickness (mm)	Cortex present/ absent	K	Ca	Ti	Mn	Fe	Zn	Rb	Sr	Y	Zr	Nb	Ba	Pb	Th	U
03-07-0043	Alca-1	flake	0.4	16	12	0.4	1	42215.3	4435	810	278	6092	46.5	160.5	92.4	12.1	97.3	12.9	248.1	19.3	10.7	
03-07-0052a	Alca-1	flake	0.2	14	7	2.5	0	48410.1	4175	905	301	6433	40.8	169.7	99.2	13.6	102.2	13.3		20.1	12.2	
03-07-0052b	Alca-1	flake	0.2	12	9	2	0	52822.0	5728	975	403	6889	58.3	182.7	103.0	13.8	106.2	14.3		21.5	14.3	
03-07-0059	Alca-1	flake	0.5	15	10	4.5	0	39737.3	9351	1236	348	7147	47.8	167.2	100.0	12.9	103.1	14.2	303.7	23.1	11.8	
01-00-0004g	Alca-4	flake	0.3	22	12	1.5	0	41086.8	7126	950	268	7016	37.7	132.7	223.7	11.4	96.3	11.4		21.4	6.5	
01-00-0004h	Alca-4	flake	0.2	15	10	1.5	0	43942.4	9376	1039	322	7493	48.3	142.7	237.2	12.6	100.0	12.7		22.0	6.2	
01-10-0001	Alca-4	flake	0.2	13	10	2	0	39333.7	6809	922	237	6731	33.5	135.3	219.1	13.4	93.8	12.8		18.1	5.1	
02-00-0001a	Alca-4	flake	0.6	11	10	3	0	34693.1	7905	873	245	6262	33.7	118.6	199.0	11.0	89.8	7.9	407.4	16.8	5.7	
02-00-0001b	Alca-4	flake	0.4	10	15	3	0	35242.4	7533	837	231	6309	34.8	121.7	199.9	11.4	87.0	8.8	341.1	18.1	6.6	
02-00-0002b	Alca-4	flake	0.3	12	10	3.5	0	37965.5	7881	935	315	6802	42.5	128.8	212.4	10.7	92.7	10.6	240.7	18.1	7.9	
02-00-0006b	Alca-4	flake	1	24	12	4	0	31361.9	7320	972	311	7799	41.6	119.1	197.3	12.1	86.9	8.7	324.0	25.2	5.9	
02-00-0006e	Alca-4	flake	0.4	10	14	3	0	35945.4	8339	921	276	6500	39.7	126.3	207.8	11.3	91.1	9.8	305.6	17.3	5.3	
02-00-0007b	Alca-4	flake	0.3	15	15	2	0	37876.9	7269	934	286	6871	34.3	130.7	219.5	12.8	96.0	12.9		17.4	7.2	
02-00-0007c	Alca-4	flake	0.4	21	12	2.5	0	43275.8	7608	918	312	6961	41.8	139.3	223.7	12.0	97.0	12.4		19.5	5.7	
02-00-0008	Alca-4	flake	0.3	14	10	2	0	39822.8	8064	905	326	7566	45.6	135.0	229.3	13.1	95.5	8.5		18.2	7.5	
02-00-0009a	Alca-4	flake	1	26	20	3	0	31922.6	7121	829	343	6154	38.9	117.4	185.4	11.5	84.8	8.3	656.7	15.3	7.2	
02-00-0009c	Alca-4	flake	2.9	23	24	7	1	37948.6	8195	821	273	6562	34.2	131.5	209.7	12.1	93.3	9.8	249.0	16.9	5.3	
02-00-0009d	Alca-4	flake	0.6	20	18	2	0	37215.8	7549	929	231	7154	38.6	133.1	208.0	12.7	91.3	10.1		20.0	7.7	
02-00-0009e	Alca-4	flake	0.3	18	12	2	0	41003.7	6774	925	265	6922	37.7	137.0	217.0	14.0	95.6	10.6		19.1	5.8	
02-00-0012a	Alca-4	flake	3	19	10	2	0	36855.7	6139	828	288	6313	37.1	111.0	179.0	12.3	82.4	7.2	386.6	18.6	6.0	
02-00-0012b	Alca-4	flake	1.3	23	20	4	0	40657.5	7340	899	278	7170	37.5	137.5	223.7	12.0	98.9	13.1		21.8	5.7	
02-00-0014	Alca-4	flake	5.1	36	28	7.5	0	33043.7	6733	796	298	6311	40.6	118.5	192.4	12.4	83.5	8.2	353.1	15.8	6.2	
02-00-0017a	Alca-4	flake	0.5	14	14	3	0	39134.8	6778	869	217	6710	35.8	129.7	212.6	13.0	95.8	11.6		19.2	6.8	
02-00-0017b	Alca-4	flake	0.2	10	15	1	0	33677.1	8639	892	267	6480	37.8	124.7	201.2	11.5	89.2	8.4	354.0	21.2	7.2	
02-00-0017e	Alca-4	flake	0.3	14	10	2	0	41430.3	8213	963	274	7506	42.2	146.0	238.7	13.3	98.7	11.9		16.7	9.3	
02-00-0024a	Alca-4	flake	1.5	16	21	7	0	30711.0	7299	814	375	6187	41.0	115.1	182.0	11.0	87.0	8.2	927.2	19.1	7.9	
02-00-0024c	Alca-4	flake	1	18	20	3	0	30842.7	6097	693	259	6001	29.9	117.0	180.9	11.5	81.1	6.0	502.9	17.4	4.2	
02-00-0024d	Alca-4	flake	0.6	11	15	5	0	33277.3	6828	848	269	6560	37.0	116.3	185.5	12.4	88.0	8.2	438.7	16.0	4.6	
02-00-0028a	Alca-4	flake	0.7	16	10	4	0	36021.3	7398	902	254	6852	37.1	124.6	206.0	10.8	90.1	10.8	254.9	21.2	5.2	
02-00-0028b	Alca-4	flake	0.6	19	15	3	0	37182.4	7658	926	274	7275	41.3	133.9	221.7	15.0	94.9	10.2		18.2	6.7	
02-00-0028d	Alca-4	flake	0.4	23	9	5	0	31717.1	6351	716	255	5974	35.2	114.0	188.5	11.4	91.5	8.2	372.6	15.2	4.7	
02-00-0032a	Alca-4	flake	0.3	15	12	2.5	0	36873.6	7513	849	260	6665	39.5	129.5	206.7	13.5	90.2	8.0	234.4	20.4	3.7	
02-00-0032b	Alca-4	flake	0.3	11	17	2	0	34547.8	7760	859	266	6547	38.0	123.8	203.0	11.1	89.3	9.4	262.9	20.6	6.0	
02-00-0032c	Alca-4	flake	1	15	15	4.5	0	37420.2	7333	910	274	7384	41.4	132.9	220.3	10.2	96.1	11.7		21.7	6.1	
02-00-0032e	Alca-4	flake	0.5	18	17	2.5	0	38999.6	8179	985	335	7378	36.2	134.1	220.5	12.5	100.2	11.1		19.7	6.8	
02-00-0032f	Alca-4	flake	0.6	20	16	2.5	0	41517.1	9329	907	348	7118	44.7	142.1	230.2	13.5	98.0	12.1		19.0	8.7	
02-00-0032g	Alca-4	flake	0.4	15	18	1.5	0	33558.2	7987	935	245	6493	37.3	122.3	194.1	10.0	86.1	8.7	385.3	17.8	6.8	

SAMPLE	Group	Type	weight (g)	length (mm)	width (mm)	thickness (mm)	Cortex present/ absent	K	Ca	Ti	Mn	Fe	Zn	Rb	Sr	Y	Zr	Nb	Ba	Pb	Th	U
02-00-0032i	Alca-4	flake	0.6	15	15	3	0	39075.2	7134	875	242	6727	38.7	130.4	213.3	12.8	93.7	11.4		16.7	7.7	
02-00-0033	Alca-4	flake	0.7	13	20	3	0	33197.3	7854	938	235	7052	34.1	119.2	197.0	11.4	90.9	7.7	330.2	16.2	7.0	
02-00-0034a	Alca-4	flake	1	18	17	6.5	0	30641.5	8001	868	430	6238	41.0	115.0	190.5	11.1	85.7	8.0	1112.1	21.9	7.1	
02-00-0034b	Alca-4	flake	0.3	12	15	2	0	32923.2	7129	993	284	7050	39.5	118.1	189.6	12.1	90.2	8.9	321.5	15.4	6.3	
02-00-0034c	Alca-4	flake	7	31	20	13.5	0	60321.8	12036	958	281	8109	43.5	138.9	232.7	13.2	99.3	13.6		28.7	7.1	
02-00-0034e	Alca-4	flake	1	15	21	7	0	37935.0	7756	877	228	6823	35.6	129.2	214.7	12.1	92.9	10.2		18.1	5.0	
02-00-0034f	Alca-4	flake	0.4	19	15	2	0	35474.1	7974	944	332	6675	33.0	122.8	201.7	10.4	92.3	10.2	318.2	19.7	6.1	
02-00-0034h	Alca-4	flake	0.4	13	15	3	0	40638.0	7431	947	303	7911	40.9	140.9	219.8	13.6	98.3	13.2		18.6	6.9	
02-00-0034i	Alca-4	flake	0.2	10	14	2	0	37710.1	7098	878	254	6678	33.6	132.8	213.6	11.4	93.7	10.1		19.0	5.8	
02-00-0034l	Alca-4	flake	0.2	15	7	2.5	0	40707.4	7253	935	235	7697	47.0	138.0	223.7	13.2	99.4	13.5		21.9	5.5	
02-00-0037b	Alca-4	flake	0.2	16	8	1	0	36447.4	7988	980	276	7465	40.6	132.6	214.6	12.9	96.2	11.1		19.3	6.2	
02-00-0037c	Alca-4	flake	0.5	20	15	1.5	0	39306.7	6870	947	212	6963	37.6	132.4	213.1	12.9	92.3	12.2		17.3	8.9	
02-00-0037d	Alca-4	flake	0.5	16	13	2	0	33930.9	8224	822	290	6552	34.6	119.9	209.5	12.8	88.8	8.5	400.7	14.6	7.2	
02-00-0037f	Alca-4	flake	0.2	7	17	1.5	0	36360.5	7801	1010	256	7623	31.8	132.1	212.2	11.6	91.8	10.6		16.7	5.4	
02-00-0037h	Alca-4	flake	0.6	15	15	4	0	37124.8	8281	1028	296	7758	39.6	134.4	219.1	11.4	97.0	10.3		22.8	7.8	
02-00-0037i	Alca-4	flake	0.3	17	11	1	0	45079.3	11865	1035	335	7247	38.0	141.4	235.1	14.5	100.6	12.0		18.7	6.4	
02-00-0037j	Alca-4	flake	0.6	10	14	4.5	0	41868.8	6462	936	362	7211	39.5	143.3	230.2	11.7	99.3	11.1		18.1	5.6	
02-00-0038	Alca-4	flake	0.4	17	15	2	0	34082.4	7413	955	258	7325	33.8	122.2	198.6	10.6	91.7	9.5	258.1	17.6	5.4	
02-00-0038b	Alca-4	flake	0.3	10	14	2.5	0	40726.9	7627	900	282	6867	36.9	134.0	223.5	11.9	94.1	10.4		18.4	5.6	
02-00-0039a	Alca-4	flake	0.3	15	15	2	0	31129.6	7236	871	333	6548	35.9	113.6	187.7	11.7	83.0	7.7	733.4	20.7	6.9	
02-00-0039b	Alca-4	flake	0.6	15	15	3.5	0	31404.7	7356	880	358	6541	40.7	113.2	185.3	11.9	85.0	9.4	749.6	18.6	7.7	
02-00-0039c	Alca-4	flake	0.3	16	15	2.5	0	37408.0	7551	914	307	7103	42.3	129.0	215.9	13.6	94.5	10.5		18.2	7.9	
02-00-0039d	Alca-4	flake	0.3	13	13	2	0	39446.6	7628	841	272	6827	39.4	133.1	221.3	13.4	96.2	11.0		18.4	7.5	
02-00-0039e	Alca-4	flake	0.3	15	15	2.5	0	32930.6	7768	885	287	6432	38.6	117.9	194.0	11.2	88.6	9.1	382.1	18.4	7.9	
02-00-0039g	Alca-4	flake	3.3	27	20	9.5	0	34593.9	7646	841	234	6563	36.4	121.0	199.8	11.1	88.5	8.7	256.6	12.2	5.4	
02-00-0039h	Alca-4	flake	0.6	16	19	1.5	0	42672.7	12662	881	328	7317	41.5	141.6	226.4	13.5	98.6	12.8		17.5	8.7	
02-00-0039i	Alca-4	flake	0.7	23	21	2	0	30953.4	7953	950	321	7054	29.5	116.5	197.5	12.9	88.9	8.5	384.6	23.2	6.6	
02-00-0039j	Alca-4	flake	0.7	17	27	3	0	35730.4	8346	1046	231	10813	39.3	130.2	215.4	12.4	94.1	9.1		20.5	5.5	
02-00-0039k	Alca-4	flake	0.7	23	14	2.5	0	35194.0	6230	877	322	6364	33.8	125.2	170.5	11.2	85.1	9.7	244.2	13.7	4.9	
02-00-0039l	Alca-4	flake	1	14	23	3	0	33660.8	8341	1003	423	6621	41.4	119.3	196.3	12.1	88.5	9.1	795.1	21.9	9.5	
02-00-0039m	Alca-4	flake	1	18	15	6	0	38045.4	11892	969	246	10739	41.0	136.6	231.0	13.3	95.3	12.3		21.8	6.4	
02-00-0039n	Alca-4	flake	0.5	19	13	6	0	34956.2	7005	827	222	6429	32.9	122.1	195.5	11.1	89.6	9.1	258.1	14.8	5.9	
02-00-0039p	Alca-4	flake	0.3	15	15	2	0	40114.6	8298	976	268	7044	39.2	138.2	225.3	12.7	97.1	12.1		20.0	7.9	
02-00-0039q	Alca-4	flake	0.5	21	15	3	0	40693.2	8011	948	279	6976	33.5	137.8	224.0	12.3	98.1	11.7		22.1	7.5	
02-00-0039r	Alca-4	flake	0.4	23	20	2	0	41526.4	7335	966	259	7084	36.0	138.3	230.5	11.6	97.1	12.3		20.1	5.9	
02-00-0041a	Alca-4	flake	0.4	15	13	1.5	0	29901.9	6106	776	261	6767	39.8	112.2	182.2	10.6	84.8	6.0	541.6	20.4	5.0	
02-00-0041b	Alca-4	flake	0.9	16	15	3	0	32931.8	8205	1014	301	7698	38.6	121.9	202.3	10.8	89.3	6.9	312.7	25.8	8.5	

SAMPLE	Group	Type	weight (g)	length (mm)	width (mm)	thickness (mm)	Cortex present/ absent	K	Ca	Ti	Mn	Fe	Zn	Rb	Sr	Y	Zr	Nb	Ba	Pb	Th	U
02-00-0041c	Alca-4	flake	1.1	18	18	6	0	31272.3	7665	982	332	7956	39.2	116.7	187.7	12.6	88.5	7.4	427.5	22.7	6.7	
02-00-0041d	Alca-4	flake	0.7	14	20	2.5	0	31293.2	8336	992	301	6786	35.6	126.3	204.5	12.8	92.7	8.5	415.0	18.8	7.1	
02-00-0041e	Alca-4	flake	1.1	22	14	5.5	0	37327.6	7877	1026	250	10667	39.4	134.3	226.0	13.7	94.2	10.7		20.1	7.7	
02-04-0002	Alca-4	flake	0.1	10	10	1	0	53335.9	14115	1194	463	8049	42.4	162.6	271.0	14.6	110.7	16.9		23.3	6.5	
02-04-0003b	Alca-4	flake	0.2	10	13	2.5	0	33242.7	62462	909	232	7000	39.8	137.4	216.6	11.9	94.0	13.3		18.9	6.3	
02-07-0009	Alca-4	flake	0.2	13	11	2	0	38676.2	8268	968	301	7021	40.8	135.1	222.7	12.6	93.8	11.1		15.4	6.2	
02-07-0010	Alca-4	flake	0.2	11	15	1	0	40289.2	7277	922	278	7863	43.0	138.7	225.1	10.9	98.0	12.0		21.9	7.0	
02-07-0016a	Alca-4	flake	0.1	9	14	1	0	47860.6	15047	845	294	5180	50.5	153.3	248.7	14.0	106.5	12.5		23.2	11.0	2.7
02-07-0016b	Alca-4	flake	0.1	10	10	1.5	0	44659.8	32152	758	394	4972	51.9	154.2	248.0	14.9	104.6	14.7		22.5	10.7	
02-07-0020	Alca-4	flake	0.3	22	9	3	0	36619.3	7904	963	285	6465	38.2	129.0	172.8	11.8	81.0	12.8		21.2	6.1	
03-00-0009	Alca-4	flake	0.5	10	15	4	0	35240.4	7931	817	297	6333	31.7	122.0	196.4	11.6	91.2	9.6	369.5	18.3	6.3	
03-07-0009	Alca-4	flake	0.8	24	10	3.5	1	34671.7	7146	779	271	6267	34.2	118.3	194.6	11.1	88.4	8.2	357.9	15.4	7.6	
03-07-0040	Alca-4	flake	0.2	10	13	2.5	0	33902.8	6192	795	130	6106	34.2	118.1	190.4	10.9	87.0	8.0	287.6	14.0	3.8	
01-00-0063a	Anillo	flake	5.5	31	21	10	1	37133.1	7488	856	297	6137	40.7	166.0	154.8	13.5	92.2	13.6	434.9	24.2	17.2	
01-00-0063b	Anillo	flake	1.7	20	15	8	0	42231.1	8113	850	356	6113	34.5	168.4	157.9	13.6	99.1	15.2	412.1	27.4	15.9	5.0
01-00-0063c	Anillo	flake	1	19	17	4	0	38180.7	8355	923	338	6358	41.2	171.3	163.1	13.7	96.1	13.6	404.1	25.5	19.5	4.9
01-00-0075a	Anillo	flake	0.6	18	15	2.5	0	38078.6	7223	830	429	6608	50.3	176.2	172.2	13.5	110.7	12.5	712.3	22.1	16.2	5.7
01-00-0075b	Anillo	flake	0.6	18	21	2.5	0	39200.7	6201	850	245	6249	36.7	172.0	167.5	14.2	105.4	13.9	318.9	21.9	18.1	4.5
01-00-0122	Anillo	flake	0.7	21	15	2	0	35816.5	7452	759	299	5858	39.1	160.3	150.7	14.6	93.3	12.6	422.5	26.2	14.8	5.6
01-10-0010	Anillo	flake	1.7	15	22	8	1	40443.1	7150	888	314	3161	42.0	179.5	165.1	12.9	113.8	5.0	683.9	23.3	17.2	4.7
02-00-0029a	Anillo	flake	2.5	23	20	6.5	0	36838.4	6253	823	357	6280	39.6	169.6	163.0	13.8	111.0	12.2	719.9	20.2	20.5	5.0
02-06-0005	Lisahuacho	flake	0.3	14	12	2	0	42717.5	10588	1212	230	7561	42.8	153.1	242.6	11.3	138.1	9.4		18.1	17.5	2.7
01-00-0008	Quispisisa	flake	1.7	26	15	6	1	38369.1	7073	821	114	5675	30.9	171.3	126.8	9.5	74.4	10.2	212.3	25.1	17.2	10.0
01-00-0034b	Quispisisa	flake	0.3	12	18	2.5	0	41564.3	7096	865	73	5829	29.6	182.2	136.4	10.8	78.4	12.6		27.8	15.3	7.4
01-00-0039	Quispisisa	flake	0.5	13	15	3	0	42520.9	8803	950	125	6177	33.1	191.6	147.2	12.1	81.5	12.9		29.0	17.9	10.6
01-00-0057a	Quispisisa	flake	0.3	10	17	2	0	45988.8	7838	1041	107	6450	30.4	205.5	155.8	11.0	84.8	15.9		31.2	20.1	9.7
01-00-0057b	Quispisisa	flake	0.3	10	16	2.5	0	40517.1	7022	909	165	5963	27.7	183.3	139.4	9.6	80.6	12.6		27.2	16.0	9.7
02-00-0004	Quispisisa	flake	0.3	10	13	2.5	0	43096.5	6455	869	117	6227	30.4	197.2	152.1	11.9	75.9	11.6		26.2	16.6	5.6
02-00-0006c	Quispisisa	flake	0.5	20	19	1	0	48931.5	6639	932	122	6846	29.7	223.1	169.2	10.5	106.1	14.3		29.4	18.8	7.9
02-00-0006d	Quispisisa	flake	0.4	14	15	1	0	52496.9	6274	846	123	7116	34.4	230.9	171.7	12.6	80.5	17.1		30.4	23.0	
02-00-0017c	Quispisisa	flake	0.5	18	17	2	0	42798.8	6169	897	134	6340	29.1	195.8	150.0	11.6	75.1	12.0		23.5	19.7	
02-00-0017d	Quispisisa	flake	0.7	15	17	3	0	53291.6	6005	1090	122	7192	35.9	236.5	180.4	12.3	109.9	18.8		31.0	23.0	4.9
02-03-0001	Quispisisa	flake	0.3	15	8	3	0	39237.0	5306	736	100	5992	30.5	190.2	142.0	10.3	73.2	12.0	136.6	22.0	18.1	8.5
02-07-0019	Quispisisa	flake	0.4	11	19	2.5	0	25388.9	111669	1035	75	6675	38.5	186.5	146.1	12.9	91.1	10.6		22.5	14.7	4.2
01-00-0017a	Alca-1	flake	0.8	18	15	3	0	39033.9	3701	782	209	5783	42.2	148.6	85.3	11.7	94.7	10.5	308.5	18.6	10.3	3.3
01-00-0018e	Alca-1	flake	0.6	17	13	2.5	0	41791.3	4116	829	242	6048	41.8	157.4	90.0	12.4	99.5	12.3	277.1	18.8	11.3	
01-00-0055a	Alca-1	flake	1.6	20	20	5	0	38683.3	6413	804	322	5695	32.5	166.6	91.7	14.5	82.5	13.4	232.8	25.2	16.0	11.4

SAMPLE	Group	Type	weight (g)	length (mm)	width (mm)	thickness (mm)	Cortex present/ absent	K	Ca	Ti	Mn	Fe	Zn	Rb	Sr	Y	Zr	Nb	Ba	Pb	Th	U
01-00-0061	Alca-1	flake	4.7	26	23	7.5	0	36315.3	5323	807	371	5634	40.8	137.1	80.1	11.2	73.5	11.5	625.2	20.3	10.7	5.8
01-00-0070	Alca-1	flake	1	20	26	2	0	41121.7	5010	879	231	5850	44.3	148.6	85.4	12.6	85.4	12.2		20.5	10.9	4.0
01-10-0002	Alca-1	flake	1	17	16	3.5	0	38779.3	11910	957	222	5930	38.8	149.8	89.4	12.5	92.7	9.3	312.4	18.0	10.5	
01-10-0008	Alca-1	flake	2.8	34	18	5	0	39690.7	4047	769	260	5819	39.2	146.5	86.3	12.1	94.6	10.4	335.3	17.7	8.7	
03-01-0009	Alca-1	flake	0.4	14	10	3.5	0	40796.6	5781	810	264	6160	43.8	152.7	91.3	12.7	97.3	10.6	300.7	17.6	10.4	
03-04-0012	Alca-1	flake	1.2	13	16	6	0	38792.1	4473	812	297	5755	41.5	145.9	85.2	10.4	92.0	10.7	547.3	16.0	10.8	3.3
03-05-0015	Alca-1	flake	1	20	14	4	0	41394.9	4241	791	243	5946	44.9	151.3	88.6	12.2	96.0	10.4	302.6	18.0	12.5	
03-05-0017	Alca-1	flake	1	16	18	4	0	40862.1	5384	894	293	5849	39.2	152.0	87.8	12.8	95.5	10.3	353.4	16.0	11.6	
03-05-0018	Alca-1	flake	2.3	32	23	3	0	34750.9	4870	802	272	5855	42.0	143.7	83.4	12.3	93.1	10.1	346.2	18.1	9.6	
03-06-0001b	Alca-1	flake	0.5	11	14	4	0	42076.4	4535	788	249	6059	45.3	154.8	90.3	13.0	104.1	11.5	291.3	16.5	12.2	
03-07-0014	Alca-1	flake	0.6	10	15	5	0	35149.5	3975	789	312	6232	47.5	151.0	87.8	13.3	92.2	10.6	558.8	18.1	10.5	
01-00-0027	Anillo	flake	1	17	16	3.5	0	39054.3	7732	837	297	6056	39.7	170.0	161.7	14.6	95.8	13.6	340.1	26.9	17.8	
01-00-0014	Alca-1	flake - bifacial thinning flake	0.2	13	15	1.5	0	52561.6	6023	1098	334	6889	49.0	175.1	104.4	14.7	94.3	18.2		27.3	14.3	7.3
01-00-0026a	Alca-1	flake - bifacial thinning flake	0.3	15	11	2	0	50420.8	4012	936	276	6674	47.0	171.5	103.2	14.1	106.3	15.1		20.5	12.3	3.2
01-00-0036e	Alca-1	flake - bifacial thinning flake	0.6	15	17	2	0	39178.5	4376	865	181	5872	42.6	145.2	82.5	12.9	80.5	11.3		21.7	9.9	3.0
01-00-0050	Alca-1	flake - bifacial thinning flake	0.3	15	10	2.5	0	44333.1	5251	901	240	6171	38.0	155.1	92.6	13.5	81.6	15.4		24.2	10.6	4.0
01-00-0051a	Alca-1	flake - bifacial thinning flake	0.6	12	22	3	0	42056.6	4610	823	185	6026	37.1	182.6	99.1	14.4	98.8	12.8		15.5	16.2	
01-00-0060c	Alca-1	flake - bifacial thinning flake	0.6	14	15	3	0	39261.6	3823	751	195	5947	38.1	152.2	89.3	12.9	93.4	11.2	279.0	17.3	11.2	
01-19-0001	Alca-1	flake - bifacial thinning flake	0.5	17	18	1.5	0	46453.7	5124	949	228	6236	44.4	162.8	97.4	12.7	88.6	16.1		21.7	12.8	3.4
03-05-0014	Alca-1	flake - bifacial thinning flake	0.6	15	13	2	0	42262.6	4517	796	226	5989	44.1	156.2	91.0	14.2	97.5	11.0	273.9	20.4	11.1	
02-00-0002a	Alca-4	flake - bifacial thinning flake	0.7	19	20	2	0	3702.7	643	204	303	6445	43.1	125.6	204.2	12.5	90.7	8.9	222.7	19.0	6.1	
02-00-0011	Alca-4	flake - bifacial thinning flake	1.2	27	20	2.5	0	35505.7	7846	841	237	6402	36.8	123.0	201.6	11.8	89.5	10.1	288.1	16.8	6.2	
01-00-0030	Jampatilla	flake - bifacial thinning flake	0.9	10	20	4.5	0	36783.6	11999	1051	416	7731	51.5	145.9	290.5	26.0	159.5	16.5	272.2	30.2	9.4	6.6

SAMPLE	Group	Type	weight (g)	length (mm)	width (mm)	thickness (mm)	Cortex present/ absent	K	Ca	Ti	Mn	Fe	Zn	Rb	Sr	Y	Zr	Nb	Ba	Pb	Th	U
02-07-0022	Quispisisa	flake - bifacial thinning flake	0.4	13	18	2	0	40147.3	7644	839	97	6158	27.4	190.4	144.6	11.6	71.5	12.0		22.8	18.3	4.6
01-00-0002	Alca-1	shatter	1.2	12	15	6	1	36271.7	5317	789	278	5588	41.6	137.0	80.1	12.0	74.8	12.7	437.0	24.0	9.9	4.8
01-00-0021b	Alca-1	shatter	1.5	16	19	6	0	38313.4	4002	764	336	5801	41.9	143.1	85.3	11.9	95.0	9.5	540.7	17.9	11.4	3.7
01-00-0042	Alca-1	shatter	0.5	11	11	4	0	37182.3	5453	819	291	5667	41.2	141.8	80.8	13.0	80.4	12.5	376.4	21.9	10.6	3.5
01-00-0048e	Alca-1	shatter	0.3	10	15	2.5	0	40636.3	5165	880	214	5842	41.7	147.9	87.1	11.5	84.2	12.6	251.6	22.3	11.7	3.2
01-00-0049	Alca-1	shatter	0.4	10	12	5	0	34514.1	4381	717	200	5464	38.6	133.6	77.0	11.6	80.2	12.0	433.4	19.5	9.8	
01-00-0073c	Alca-1	shatter	0.5	13	15	3	0	40807.2	4807	886	219	5813	37.4	148.4	83.0	12.1	77.1	14.0		20.3	10.5	4.6
01-05-0003	Alca-1	shatter	1.2	20	16	5	0	37569.4	6462	783	247	5576	31.3	163.8	88.1	13.7	80.6	14.2	233.9	23.1	13.8	5.5
01-06-0002	Alca-1	shatter	0.5	16	11	19	0	43444.7	4593	1004	242	6221	44.9	163.6	91.4	12.1	99.9	10.5	251.1	17.5	11.8	3.6
01-10-0004	Alca-1	shatter	1.2	11	16	5.5	0	39363.8	4941	770	376	5922	44.0	150.8	87.8	12.5	94.6	10.4	751.6	21.2	12.4	3.3
03-00-0001a	Alca-1	shatter	2.7	15	20	10.5	0	37895.9	3379	673	438	5595	47.4	137.9	75.5	11.7	87.6	10.0	948.0	17.6	11.6	
03-00-0011a	Alca-1	shatter	2.2	15	30	5	0	48256.1	4599	775	332	5990	47.2	150.7	85.0	14.5	99.1	11.0	501.7	18.1	10.3	
03-00-0011b	Alca-1	shatter	1.1	14	21	8.5	0	54066.2	4230	768	287	6000	44.9	155.0	90.2	13.2	93.5	11.9	335.9	19.0	12.2	
03-00-0011d	Alca-1	shatter	1.1	10	19	7.5	0	35075.8	4037	690	395	5780	46.3	145.6	87.2	12.9	94.5	11.4	1060.0	20.6	12.5	
03-03-0001	Alca-1	shatter	1	13	24	6	0	33243.9	5881	886	365	5961	49.2	140.3	82.5	11.4	93.5	9.6	578.3	19.3	11.4	
03-04-0003	Alca-1	shatter	1	13	17	7.5	0	43653.7	6071	779	398	6243	47.6	161.0	94.0	13.0	98.6	12.9	643.0	20.4	13.6	
03-04-0021	Alca-1	shatter	0.5	7	15	4	0	40915.0	6965	796	287	6020	45.3	155.1	90.6	13.5	73.1	11.0	378.1	20.2	13.0	2.7
03-05-0003	Alca-1	shatter	0.9	12	20	4	0	39735.4	4471	754	299	5811	43.5	148.6	85.8	13.9	101.2	11.1	346.8	16.5	9.9	
03-05-0010	Alca-1	shatter	0.3	17	6	3.5	0	48297.8	4478	923	260	6387	45.2	173.3	101.7	15.4	100.7	14.2		20.2	12.9	
03-05-0016	Alca-1	shatter	0.2	11	7	2	0	49575.0	3178	902	342	6897	51.5	177.4	102.9	13.1	110.2	14.1	212.0	21.9	14.9	
03-06-0003	Alca-1	shatter	1.7	22	22	7	0	52110.7	4385	777	270	5706	42.9	143.8	84.5	13.5	91.7	9.7	539.3	17.8	9.4	2.8
03-07-0039	Alca-1	shatter	0.3	11	8	4	0	42206.6	3387	818	236	5787	40.3	148.7	85.9	11.3	86.5	11.3	320.9	16.1	10.7	
01-00-0004a	Alca-4	shatter	1	20	11	4	0	32498.5	7348	840	283	6330	40.0	117.1	191.0	12.0	85.1	7.9	417.1	19.1	5.1	
01-00-0004b	Alca-4	shatter	1.2	20	12	7.5	0	30684.6	6714	787	351	6280	35.8	116.4	184.2	11.2	85.4	7.4	674.7	17.9	6.6	3.0
01-00-0004c	Alca-4	shatter	1.4	19	12	6	0	32938.0	7588	764	375	6233	39.4	114.1	191.2	11.7	87.7	8.1	718.5	19.0	6.4	
01-00-0004d	Alca-4	shatter	1.2	12	16	5.5	0	32491.6	7268	770	362	6194	38.6	115.2	190.0	11.5	85.9	7.7	745.8	17.5	7.4	
01-00-0004e	Alca-4	shatter	1.3	19	10	8.5	0	31719.6	7141	862	378	6473	39.0	116.1	186.9	10.7	84.9	7.7	774.3	18.0	6.9	
01-00-0004f	Alca-4	shatter	0.4	15	12	2	0	41126.7	6824	916	271	6997	37.5	132.9	223.6	12.5	94.8	11.9		19.5	6.8	
01-00-0004i	Alca-4	shatter	0.4	13	8	4	0	38837.5	9482	1031	414	7260	44.6	116.3	226.9	12.1	96.6	9.9	425.0	20.8	8.2	
02-00-0009b	Alca-4	shatter	4.5	38	18	8	0	40648.3	7225	870	316	6376	39.4	116.7	188.8	11.6	84.2	7.7	444.9	21.7	6.0	
02-00-0024b	Alca-4	shatter	2.5	15	23	7	0	33738.5	9049	1202	392	7514	39.9	124.6	208.6	13.7	93.4	10.1	379.2	20.5	7.7	
02-00-0034g	Alca-4	shatter	0.5	14	12	4	0	34778.1	7689	949	283	7109	36.3	127.8	214.6	10.9	92.3	12.1	282.2	18.4	5.9	
02-00-0039f	Alca-4	shatter	6.4	17	21	11.5	0	33979.4	7305	962	262	7238	36.4	125.3	204.9	12.7	92.4	10.9		23.2	7.9	
02-00-0039o	Alca-4	shatter	1.4	15	15	8.5	0	37602.4	6705	900	224	6552	38.5	127.9	214.3	12.5	92.6	10.9		17.2	5.0	
02-07-0014	Alca-4	shatter	0.8	10	22	3	0	35138.7	9171	1076	306	6932	37.2	124.4	204.4	10.4	90.9	9.1	301.4	16.7	5.3	
03-07-0002	Alca-4	shatter	0.4	8	15	4	0	36124.7	7438	866	272	6473	38.2	125.8	205.3	12.0	88.6	8.7	318.4	17.1	6.0	

SAMPLE	Group	Type	weight (g)	length (mm)	width (mm)	thickness (mm)	Cortex present/ absent	K	Ca	Ti	Mn	Fe	Zn	Rb	Sr	Y	Zr	Nb	Ba	Pb	Th	U
02-03-0002	Quispisisa	shatter	0.2	8	14	3	0	46830.1	6765	904	144	6490	33.5	213.2	161.6	12.8	81.8	12.4		23.2	17.5	6.2
9003.1.3	Geologic Quispisisa							36265.9	6477	883	177	5753	34.5	177.1	134.9	10.7	90.7	2.9	485.5	28.7	18.2	5.3
9003.2.2	Geologic Quispisisa							37767.6	7093	919	321	5769	34.7	182.2	139.3	11.7	91.7	3.9	672.8	24.0	18.7	7.3
9004.2.3	Geologic Quispisisa							36025.7	6566	849	307	5564	32.5	179.4	135.6	10.7	88.0	1.0	701.5	24.5	19.9	6.4
9004.3.4	Geologic Quispisisa							36701.9	6531	897	281	5647	31.2	181.5	136.2	10.2	87.3	3.3	625.8	24.3	18.5	5.9
9006.1.5	Geologic Quispisisa							37274.5	6799	912	295	5731	31.9	178.6	136.2	10.2	85.0	3.4	761.3	23.8	20.2	7.1
9006.2.2	Geologic Quispisisa							38002.8	6580	864	269	5244	30.7	190.3	138.9	14.2	91.0	2.8	721.9	27.0	19.0	11.0
9006.3.2	Geologic Quispisisa							37726.2	7092	942	320	5540	33.0	183.9	140.5	11.8	89.0	3.8	748.0	27.2	20.3	7.1
9006.4.3	Geologic Quispisisa							37235.3	6497	903	264	5500	32.0	183.0	139.6	11.0	87.5	3.2	504.0	24.5	16.5	6.5
9006.5.2	Geologic Quispisisa							35823.8	5879	793	185	5351	27.9	179.2	136.0	11.3	84.9	3.7	529.3	22.1	17.7	6.9
9007.2.4	Geologic Quispisisa							37326.6	6897	903	210	5631	35.0	185.2	139.8	11.6	88.4	3.7	531.0	24.4	17.7	6.8
9029.2.2	Geologic Quispisisa							36594.3	6225	811	171	5428	28.4	186.1	137.0	9.6	88.7	3.1		26.5	15.8	5.8
9029.5.2	Geologic Quispisisa							35331.2	5324	755	296	5415	34.0	173.3	134.2	11.8	85.6	1.9	754.6	21.9	18.6	6.0
9031a.3.3	Geologic Quispisisa							35175.0	5679	776	339	5910	31.9	176.0	132.5	11.6	86.8	3.4	811.0	22.8	19.1	7.8
9031a.5.3	Geologic Quispisisa							35710.8	6382	1031	221	5438	33.8	177.8	133.9	11.1	85.4	3.6	556.9	24.8	19.6	7.4
9031a.7.3	Geologic Quispisisa							37463.2	7088	899	232	5304	30.3	187.4	137.0	10.5	87.4	3.9	642.3	29.2	18.1	7.0
9087.1.3	Geologic Quispisisa							33863.7	5673	774	201	5494	27.5	169.2	131.4	11.2	86.5	2.0	667.9	25.8	16.9	5.7
9005.1.2	Geologic Quispisisa							36788.3	6607	881	282	5679	35.7	181.7	137.1	11.2	88.6	2.8	778.7	26.1	17.1	7.2
9007.3.4	Geologic Quispisisa							37275.1	6781	887	347	5723	41.7	187.5	139.2	9.7	90.5	3.2	666.9	24.8	17.9	8.5
QSS001	Geologic Quispisisa							34547.1	4944	746	269	5826	32.7	175.3	132.9	11.3	73.9	9.2	733.7	23.7	15.7	8.2
Alca1-KRA-001	Geologic Alca-1							36978.5	3756	723	422	5751	47.4	139.1	81.9	12.4	90.4	9.9	1019.7	17.1	12.5	5.1
Alca1-KRA-026	Geologic Alca-1							36572.4	4268	800	421	5907	53.8	143.0	83.4	13.1	89.5	9.8	934.9	19.1	11.1	4.4
ALCA1-kra061	Geologic Alca-1							36812.2	5364	842	452	2793	44.6	143.1	84.0	11.2	85.9	4.0	1043.6	19.7	12.3	3.8
Alca1-KRA-065	Geologic Alca-1							37810.6	4095	743	406	5811	49.3	145.3	83.2	13.3	93.5	10.5	993.2	19.1	11.2	4.4
Alca1-KRA-070	Geologic Alca-1							36016.6	3990	743	468	5754	47.1	143.9	83.2	12.4	90.5	10.4	983.8	18.7	10.8	5.6
Alca1-KRA-095	Geologic Alca-1							37288.4	4154	763	440	5795	46.3	143.4	83.4	12.8	84.0	10.2	973.0	19.0	12.3	5.5

SAMPLE	Group	Type	weight (g)	length (mm)	width (mm)	thickness (mm)	Cortex present/ absent	K	Ca	Ti	Mn	Fe	Zn	Rb	Sr	Y	Zr	Nb	Ba	Pb	Th	U
ALCA1-KRA113	Geologic Alca-1							36924.8	4282	791	477	2725	45.1	138.1	85.7	12.8	96.2	3.4	1081.3	21.6	13.3	5.5
Alca1-M25	Geologic Alca-1							37119.6	4051	748	420	5802	50.6	145.0	82.5	12.4	89.6	10.0	966.2	20.4	11.7	5.4
ALCA1-m94	Geologic Alca-1							36393.6	5407	865	368	2774	45.8	140.7	87.4	12.9	95.7	3.1	976.1	22.4	11.4	3.2
Alca2-KRA-003	Geologic Alca-2							35616.6	5676	1167	420	7196	51.1	147.5	153.8	13.7	151.0	10.7	944.1	17.1	15.3	5.3
Alca2-KRA-004	Geologic Alca-2							35654.7	5355	1085	429	6754	49.4	149.2	150.8	13.7	146.0	10.3	978.4	21.5	15.1	5.3
Alca2-KRA-151	Geologic Alca-2							36978.0	5480	1099	425	6660	51.8	150.1	149.0	13.0	148.8	11.2	1006.7	20.2	14.7	5.2
Alca3-KRA-010	Geologic Alca-3							35414.6	7873	1219	554	7246	53.6	134.0	233.5	14.8	147.1	9.7	1029.3	19.0	12.2	3.7
Alca3-KRA-011	Geologic Alca-3							34989.4	7839	1179	515	7341	54.2	133.0	229.1	14.1	148.1	9.5	997.5	21.8	11.9	5.0
Alca3-KRA-012	Geologic Alca-3							33786.4	8201	1169	516	7215	53.7	133.7	232.7	14.1	147.0	9.8	995.7	20.0	10.9	4.9
Alca3-KRA-013	Geologic Alca-3							34144.6	7938	1172	543	7163	51.8	133.3	232.0	13.7	156.5	9.1	1075.0	20.0	10.4	4.9
Alca3-KRA-094	Geologic Alca-3							33531.1	7924	1190	528	7256	54.1	136.3	230.3	14.2	146.0	9.8	1047.9	20.1	11.6	4.3
Alca3-KRA-161	Geologic Alca-3							33305.1	7772	1163	455	7130	47.9	134.5	231.7	13.8	147.5	9.4	864.4	19.1	11.3	4.9
Alca3-KRA-162	Geologic Alca-3							33420.2	7936	1181	506	7218	56.2	134.2	234.7	14.6	146.8	10.5	1021.2	18.7	12.6	4.8
Alca3-KRA-164	Geologic Alca-3							33449.2	8410	1208	509	7268	53.5	134.2	231.8	13.9	146.8	9.7	990.4	27.3	11.1	5.4
Alca4-KRA-097	Geologic Alca-4							29172.9	6621	963	522	6483	46.5	115.7	163.8	11.5	89.0	8.2	1067.1	26.5	5.1	
Alca4-KRA-098	Geologic Alca-4							30634.0	6377	790	519	6144	45.5	114.3	160.7	11.6	83.4	7.7	1040.1	22.5	5.5	4.5
ALCA4-kra099	Geologic Alca-4							31485.4	6832	860	437	3446	46.5	108.0	169.9	12.8	87.8	0.6	1160.9	19.9	8.1	4.1
Alca4-KRA-100	Geologic Alca-4							30649.7	6545	837	493	6168	45.6	112.6	161.4	12.3	87.0	8.0	1053.7	23.9	6.5	3.6
ALCA4-kra242(1)	Geologic Alca-4							30846.6	7035	802	426	3079	41.1	109.6	169.2	11.4	85.7	1.2	1019.3	17.7	7.0	3.0
ALCA4-kra242(2)	Geologic Alca-4							31072.4	6995	793	544	2894	35.3	111.0	169.8	11.9	83.5	-0.6	1126.1	18.3	8.8	4.3
Alca4-KRA-252	Geologic Alca-4							30341.3	6648	856	506	6021	45.4	114.8	155.9	11.5	85.9	8.5	1049.5	24.0	5.4	4.0
ALCA4-KRA-254	Geologic Alca-4							30088.0	6191	839	507	6055	45.0	116.0	159.8	11.8	88.1	8.1	1016.8	18.4	6.9	3.3
Alca4-KRA-257	Geologic Alca-4							29657.8	6596	858	510	6124	43.9	113.9	160.6	12.1	86.7	7.6	1042.2	23.7	6.2	4.2
ALCA5-KRA-107	Geologic Alca-5							34009.1	4549	750	427	5693	42.2	133.3	116.7	11.1	58.1	10.1	825.1	18.3	9.2	5.1
ALCA5-KRA-108	Geologic Alca-5							35677.6	5033	804	465	5811	48.3	136.8	119.2	13.2	62.6	9.7	996.2	20.1	12.7	4.6
ALCA5-KRA-109	Geologic Alca-5							35984.9	5128	768	351	5782	41.3	136.3	121.6	11.5	73.2	9.1	599.2	17.6	10.2	3.3
ALCA5-KRA-110	Geologic Alca-5							34626.1	4764	735	317	5666	42.2	133.9	119.2	11.6	74.1	9.8	446.9	15.9	10.4	4.0
ALCA5-KRA-111	Geologic Alca-5							34718.0	4895	761	465	5810	44.1	135.2	120.1	12.6	69.0	10.5	991.4	20.9	11.7	5.0
ALCA5-KRA-112	Geologic Alca-5							36215.9	5131	798	461	5832	46.5	136.7	119.3	13.5	66.3	9.9	910.8	18.6	10.9	4.0
ALCA7-KRA-101	Geologic Alca-7							34490.1	6354	751	422	5706	37.3	159.1	147.6	13.0	58.0	10.9	817.7	23.4	15.2	5.7
ALCA7-KRA-102	Geologic Alca-7							35541.9	6799	735	437	5747	34.0	161.5	147.0	13.7	58.8	10.1	837.1	23.5	13.8	4.7
ALCA7-KRA-189	Geologic Alca-7							35447.2	6382	722	444	5711	34.9	162.0	147.8	13.5	59.2	11.1	758.2	21.4	14.8	5.8
ALCA7-KRA-195	Geologic Alca-7							34764.9	6572	751	434	5790	35.8	159.6	146.1	13.8	60.5	11.0	768.1	24.6	15.4	5.7
ALCA7-KRA-197	Geologic Alca-7							34966.6	6298	761	374	5732	31.0	162.6	144.5	13.1	57.6	10.1	701.5	20.8	14.5	5.3
ALCA7-KRA-198	Geologic Alca-7							35297.5	6454	735	377	5691	33.5	160.7	139.9	13.4	57.5	9.9	650.3	21.5	16.4	5.8
ALCA7-KRA-205	Geologic Alca-7							35227.4	6084	746	393	5648	36.3	163.2	141.4	13.0	57.2	10.6	611.7	21.5	15.7	5.2
Arpu01	Geologic Chivay							37756.5	4755	627	583	5017	41.0	243.5	46.7	18.1	72.5	19.9	184.6	25.7	21.1	9.2

SAMPLE	Group	Type	weight (g)	length (mm)	width (mm)	thickness (mm)	Cortex present/ absent	K	Ca	Ti	Mn	Fe	Zn	Rb	Sr	Y	Zr	Nb	Ba	Pb	Th	U
Arpu02	Geologic Chivay							37268.8	4659	618	563	4960	48.0	245.3	45.6	16.9	71.6	19.2	227.5	23.4	21.8	6.7
Arpu03	Geologic Chivay							35992.8	4733	798	672	5795	42.6	240.2	46.3	16.6	73.0	19.6	198.5	25.1	21.7	7.1
Arpu04	Geologic Chivay							33331.6	4359	745	555	5240	47.4	241.3	46.8	17.0	71.9	18.0	220.7	22.5	19.6	8.2
Arpu05	Geologic Chivay							36494.2	4673	607	593	4907	39.7	242.7	44.5	16.2	70.0	18.3	238.7	23.0	21.2	7.7
Arpu06	Geologic Chivay							37823.0	4722	587	596	5083	41.5	247.2	46.4	16.0	73.7	19.9	178.8	23.8	20.8	8.9
CHV001	Geologic Chivay							34945.6	4085	613	646	5588	41.2	242.5	45.4	17.0	60.0	19.2	176.1	27.8	21.2	7.7
LPP001	Lisahuacho geologic							42318.3	7865	958	339	8732	54.4	160.5	291.3	12.4	159.1	12.8	756.5	26.9	16.9	5.5
LPP002	Lisahuacho geologic							41702.2	7652	969	384	8570	58.6	157.8	285.4	11.8	158.6	12.8	721.0	27.9	17.6	3.8
LPP003	Lisahuacho geologic							41935.6	7721	942	369	8648	55.6	162.0	288.9	12.3	158.2	12.7	606.3	25.5	17.7	3.6
LPP004	Lisahuacho geologic							40862.3	7399	925	374	8414	59.0	156.9	280.7	11.9	156.0	13.2	878.9	27.1	20.0	4.6
LPP005	Lisahuacho geologic							42456.0	7816	948	319	8730	57.9	159.9	291.9	11.8	166.1	13.3	622.6	25.3	16.8	4.4
ANI7151-1-1	Anillo geologic							37200.3	6086	779	340	6057	39.6	174.2	157.8	14.1	112.7	13.3	727.3	21.1	20.0	6.2
ANILLO7151.1.2	Anillo geologic							37104.8	6966	889	451	3224	44.2	173.3	165.6	14.7	115.3	6.5	1068.2	23.0	20.1	4.8
NT0057	Anillo geologic							37733.2	6382	778	388	6166	51.7	178.4	164.7	14.1	111.8	12.6	739.6	20.6	19.9	6.5
NT0062	Anillo geologic							38196.3	6550	775	418	6180	48.3	177.6	164.1	14.1	108.4	12.8	776.9	21.2	20.5	5.6
NT0063	Anillo geologic							39816.5	6675	805	425	6209	45.4	178.1	166.9	13.9	114.2	11.8	745.5	18.9	19.4	7.8
NT0065	Anillo geologic							37874.7	6586	794	333	6450	51.2	179.3	172.3	14.5	113.3	13.2	527.1	20.2	19.5	5.5
PPP001	Potreropampa geologic							38422.5	5153	556	384	4615	39.9	166.7	83.9	14.3	63.1	13.3	361.2	26.7	15.6	6.5
PPP002	Potreropampa geologic							42851.2	5514	587	400	4744	40.8	171.1	83.4	14.0	64.5	13.8	348.8	23.1	15.1	5.4
PPP003	Potreropampa geologic							39887.2	5718	580	372	4789	69.0	173.3	87.2	13.5	63.3	15.1	237.2	21.8	17.4	5.1
PPP004	Potreropampa geologic							44635.4	5387	553	343	4678	40.7	169.0	84.6	13.3	61.8	13.4	249.0	20.9	15.9	5.0
PPP005	Potreropampa geologic							39073.5	5423	562	293	4721	38.8	171.9	83.2	13.1	65.0	14.5	154.6	20.8	16.2	5.3
rlb039	Jampatilla geologic							35366.3	10843	1094	552	8847	70.6	163.3	284.1	25.7	153.6	18.0	666.6	27.1	13.4	6.1
rlb040	Jampatilla geologic							33851.7	10118	983	410	8476	57.0	159.0	273.6	25.3	153.6	17.3	664.6	25.5	12.4	7.2
rlb041	Jampatilla geologic							35258.1	11332	1065	505	8631	57.4	163.1	284.1	25.2	154.3	16.8	614.1	27.9	13.3	5.9
rlb042	Jampatilla geologic							35233.9	11007	1027	378	8927	57.6	161.9	284.5	24.9	152.9	18.3	402.1	27.1	12.8	5.6
rlb043	Jampatilla geologic							34788.5	11289	1062	494	8696	61.2	164.5	281.2	24.9	154.9	17.5	613.9	28.8	12.1	5.5
rlb044	Jampatilla geologic							34217.1	10265	982	464	8614	66.8	160.6	277.9	24.2	149.8	17.2	577.8	25.8	11.5	6.0

Chapter 10

Obsidian Utilization in the Moquegua Valley through the Millennia

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Abstract

We review obsidian acquisition and utilization at sites in the Moquegua Valley, Peru from the Formative Period through the Late Horizon (*c.* 0–1500 CE). We examine sources represented through time, as well as quantities of obsidian recovered from excavation contexts at a variety of sites excavated by the authors (MAS survey, Cerro Baúl, Cerro Mejía, Yahuay Alta, Tumilaca la Chimba, Capanto, Las Peñas, Sabaya, Torata Alta, Camata, and Tacahuay). Our results indicate that the Middle Horizon (600–1000 CE) was the principal period of obsidian use in the region, and that fall-off models indicate that Cerro Baúl served as a centralized distribution center for obsidian from the major sources during this time. Despite the importance of obsidian in other Andean regions during periods outside the Middle Horizon, our data indicate that the Moquegua region participated only tangentially in obsidian procurement in the absence of the Wari state, and that even the Inca Empire did not make obsidian a principal product of exchange during its apogee.

Introduction

The Moquegua valley in southern Peru is one of the more prevalent small valleys on the western watersheds of the Andes. It has been the subject of intensive archaeological investigation for four decades and as a result, provides a unique case study for obsidian utilization through time. In recent decades, dozens of archaeological sites have been surveyed or excavated by the authors. In the case of excavations, we have employed a similar high precision methodology for recovery of micro-artifacts and debitage at archaeological sites. The sites we have investigated span two millennia of principally farming communities under differing political hegemonies. The differential use of obsidian in these settlements provides perspective on the role obsidian played in the political economy of different societies through time.

In the South-Central Andes, archaeologists note that farming and irrigation agriculture began as early as the second millennium BCE (Formative Period). It was not until the first millennium CE, however, that early state societies began colonizing the Western valleys of southern Peru. Among these were the Middle Horizon states of Wari and Tiwanaku. These rival entities expanded along the spine of the Andes' mountains from Cajamarca to Moquegua in the case of Wari, and from the eastern valleys of Bolivia to the western valleys of Moquegua and south in the case of Tiwanaku. The Moquegua valley is the primary locale of dual colonization by both entities over the course of four centuries.

After the collapse of the Middle Horizon states, balkanized polities emerged, including the archaeological cultures of Tumilaca, Chiribaya, and Estuquiña in the Moquegua Valley. Elsewhere, the Colla, Lupaca, and Pacajes cultures held sway, and in the Cusco region, the Inca arose. This was the Late Intermediate Period landscape of competition and scarce water resources that heralded periods of rivalry and warfare, with the Inca arriving as victors and beginning the conquest of much of the Andean mountains from Ecuador to Chile. The Inca consolidated power across the Andes in the

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Late Horizon, establishing the New World's largest indigenous empire.

The dataset we employ to address the role of obsidian in sociocultural development is the result of forty years of fieldwork in the valley by the authors and by early colleagues in the Contisuyo research program. We sample sites from time periods ranging from the Formative Period (2000 BCE – 600 CE), Middle Horizon (600 – 1000 CE), Late Intermediate Period (1000 – 1400 CE) and Late Horizon (1400 – 1532 CE), and our sample includes both surface survey as well as excavated contexts. We have incorporated sites excavated from each time period using a similar excavation recovery methodology to ensure comparability. The excavated sample does not rely only on sites from which obsidian was recovered, since the absence of obsidian use is an important data point for our analysis as well.

We begin by examining the sources of obsidian through time, noting relative abundance at different settlements and comparing the distribution of source material at contemporary sites with the most material to that with the least material. Methods of analysis and instrumentation are the same as those detailed in Reid *et al*. (this volume). Our analysis illustrates that obsidian was scarce in settlements prior to 600 CE and was represented by sources relatively close to the valley (within *c.* 200 kilometers distance). Between 600 and 1000 CE, obsidian procurement exploded in the valley, and is strongly correlated with the expansion of the Wari state. Wari state sites have the most obsidian, and it predominantly is associated with sources closer to the Wari capital and affiliated with Wari state distribution networks. Obsidian use drops off precipitously in the Late Intermediate Period, with only a few pieces recovered in extensive excavations and none of them have been sourced. The Late Horizon is also only represented by four obsidian fragments across five excavated sites.

In order to model obsidian use, we turn to an analysis of excavated obsidian, including debitage too small for sourcing via pXRF. We examine the average weight per implement, density of obsidian objects and debitage, and ubiquity of obsidian across settlements to assess the relative importance of obsidian in each community. This analysis is most illuminating for the Middle Horizon period when obsidian was an important commodity. We collect the same data for the earlier Formative period and the Late Intermediate and Inca periods, though the data principally illustrate the paucity of obsidian use during these times. For the Middle Horizon, measures of obsidian density, average implement weight, and ubiquity demonstrate that the Wari state settlement on the summit of Cerro Baúl had the largest obsidian objects with the highest density of material and the greatest ubiquity of obsidian across the settlement among all sites sampled. The smallest pieces of obsidian, regardless of source, with the lowest densities and ubiquities on site for the time period were the Tiwanaku related settlements around Cerro Baúl. Even these Middle Horizon settlements, though, eclipsed the statistics for obsidian presence in the Formative, LIP, and Late Horizon sites in the sample. That is, even the most challenged obsidian users of the Middle Horizon had greater access than their predecessors or successors.

Our assessment of obsidian prevalence provides new data on how obsidian distribution and consumption can be modeled across a region (see Ortega *et al.* 2013; Renfrew 1975; Torrence 1986 for a Neolithic perspective). It is dependent on the rich and extensive excavated dataset that has been developed over four decades in the study region, and so will not be applicable in regions without this level of research fieldwork. Nonetheless, the nuanced data it provides illustrates how states can set up hierarchical distribution networks that dominate an economic assemblage, but also co-exist with more dispersed economic networks that supply sites not participating in the state system. This shadow economy or secondary network provides goods that have become important under the economic forces driven by the politics of the primary state to those operating on the margins of that network, or outside of it entirely. The prevalence of diverse obsidian sources in the Tiwanaku settlements follows this model. In order to assess the assertions here, we now turn to a description of the sites represented in our analysis.

Sites Represented in the study

We compile data from dozens of archaeological sites in the study that have been part of systematic archaeological investigation by the authors. Some were only investigated superficially through pedestrian survey, while fourteen were systematically excavated, often through extensive area excavations of activity areas measuring hundreds of square meters (Figure 10.1; Tables 10.1, 10.2). These fourteen excavated sites range from the Formative Period through the Late Horizon and are dispersed throughout the temporal sequence with a slight bias to Middle Horizon settlements (note that only sites with sourced obsidian recovered are listed in Table 10.1 and some sites in Table 10.1 are split into distinct sectors). This is supplemented by sites more representative of other time periods in the middle valley Moquegua Archaeological Survey directed by Goldstein.

Table 10.1. Obsidian sources by site (excavated sites without sourced obsidian: Capanto, Las Peñas, Colorado Mogoté, Sabaya, Torata Alta, Camata, Tacahuay, and Punta Picata); FM: Formative Period, MH: Middle Horizon, LIP: Late Intermediate Period, LH: Late Horizon[1]

Site	Alca-1	Alca-4	Alca-5	Alca-7	Anillo	Chivay	Quispisisa	Potreropampa	Unknown	Total
Recovered in Excavations (pXRF)										
Yahuay Alta FM	0	0	0	0	0	0	0	0		0
Yahuay Alta MH	19	0	0	0	0	2	3	0		24
Cerro Baul MH	205	0	0	0	1	10	33	2		251
Baul Slopes MH	8	0	0	0	0	5	7	0		20
Cerro Mejia MH	22	0	0	0	0	0	14	5		41
Mejia Slopes MH	42	6	2	2	0	4	29	0		85
El Paso MH	1	0	0	0	0	0	1	0		2
Tumilaca la Chimba MH	19	0	0	0	1	11	8	7		46
Chen Chen MH	0	0	0	0	0	1	0	0		1
Omo MH	8	1	10	0	3	2	6	0	1	31
										501
Collected in Archaeological Survey (pXRF)										
Calaluna Montalvo FM						2				2
Huaracane FM						1				1
Perro Muerto FM	1					1				2
Que Calor FM	1					1				2
Tres Quebradas FM						2				2
Yanahuara FM	1									1
Cerro Echenique MH	2					1				3
Cerro Trapiche MH	5									5
										18
Collected in Archaeological Survey (INAA) - Burger et al. 2000										
Cerro Baul MH	70	0	0	0	0	3	7	8		88
Omo MH	2	0	0	0	0	2	1	3		8
										96
									TOTAL	615

[1] While a new classification for the Alca sources has recently been proposed (see Burger *et al.* 2021), results here are based on traditional source classifications for the region.

Table 10.2. Obsidian Average weight, Density and Ubiquity in several of the collections excavated by the authors (not represented: Omo and Chen Chen)

Collection	Sector	Ct	Wt (g)	Avg Wt (g)	m2 excavated	count/m2	g/m2	ubiquity
Yaway FM		0	0.00	0.00	237	0.00	0.00	0.00
Yaway MH		77	60.82	0.79	320	0.24	0.19	0.10
MH Sites								
Baul02	A	308	347.00	1.13	297	1.04	1.17	0.47
Baul02	C	49	108.70	2.22	44	1.11	2.47	0.55
Baul02	K	74	39.80	0.54	61	1.21	0.65	0.62
Baul02	L	7	18.10	2.59	86	0.08	0.21	0.05
Baul02	N	8	1.30	0.16	86	0.09	0.02	0.07
Baul02	FGHI	6	1.20	0.20	222	0.03	0.01	0.04
Mejia 2000, 8–9	Slopes	1505	148.98	0.10	702	2.14	0.21	0.36
Mejia 2000, 2011	Summit	779	141.64	0.18	591	1.32	0.24	0.26
Tumilaca la Chimba (sourced only)		46	57.90	1.26				
Tumilaca Phase (all material)		96	67.70	0.71	292	0.33	0.23	0.21
Estuquiña Phase		1	0.10	0.10	245	0.00	0.00	0.004
LIP Sites								
Colorado Mogote/Las Peñas/Capanto		0	0.00	0.00	>1000	0	0	0
LH (Inca) Sites								
Sabaya & Torata Alta		3	12.50	4.17	>200	<.02	<.03	<.015
Camata		0	0.00	0.00	>200	0	0	0
Tacahuay & Punta Picata		1	0.80	0.80	>200	<.005	<.005	<.005

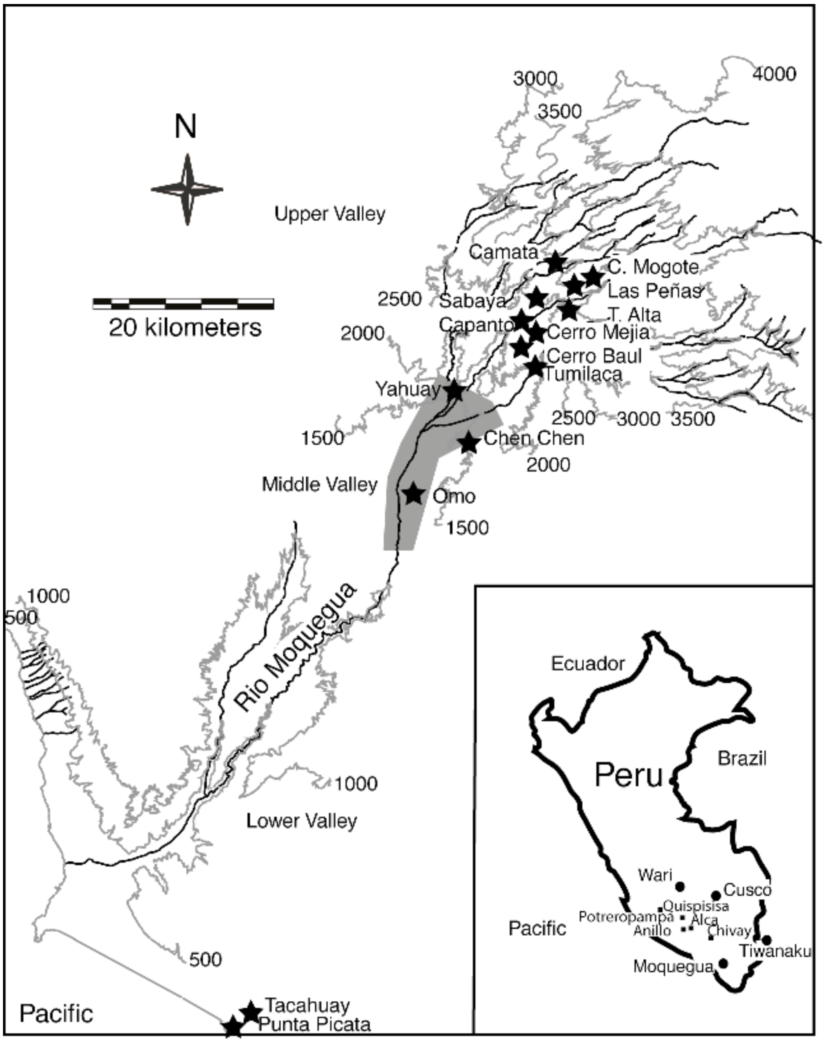

Figure 10.1. Map showing excavated sites and the MAS survey region (in gray) represented in this study. Location map shows study region in reference to principal obsidian sources and the ancient capital cities of Wari, Tiwanaku, and Cuzco.

The Middle Valley settlements (Omo, MAS survey and Contisuyo Collections)

The Middle Valley obsidian assemblage is represented by both excavated and surface collected archaeological materials (Reid *et al.* i.p.), including Goldstein's excavations at the Tiwanaku site of Omo (Goldstein 1989, 1993, 2013, 2015; Goldstein and Sitek 2018) and the residential sectors at Chen Chen (Goldstein and Owen 2001, Goldstein 2005). The dataset also includes obsidian collected during surface survey of the Moquegua Archaeological Survey (MAS), directed by Paul Goldstein, and by other surveys and excavations conducted by the Programa Contisuyo. These include the Formative Period sites of Perro Muerto, Que Calor, Tres Quebradas, Yanahuara, and Calaluna Montalvo from the MAS survey and Huaracane from Contisuyo collections. The Contisuyo collections from Cerro Echenique and MAS collections from Cerro Trapiche are complemented by Goldstein's excavations at Omo for the Middle Horizon data set. The largest group of obsidian recovered in this data set comes from the Tiwanaku site of Omo M16, with 28 obsidian objects sourced (Reid *et al.*, i.p.).

Yahuay Alta

Yahuay Alta is situated high upon the southwestern flanks of Cerro Estuquiña, one of the mountains that demarcates the boundary between the upper and middle valley sections of the Moquegua valley. The site was excavated by Costion in 2006 (2009, 2013) and had both Formative Period and early Middle Horizon occupations. Yahuay Alta was an atypical Huaracane settlement in that it is located at a significantly higher elevation above the riverbed in comparison to typical Huaracane settlements in the middle valley. Yahuay Alta is also the only Huaracane settlement with large-scale public architecture in the form of a monumental platform mound-plaza complex (see Costion 2013:

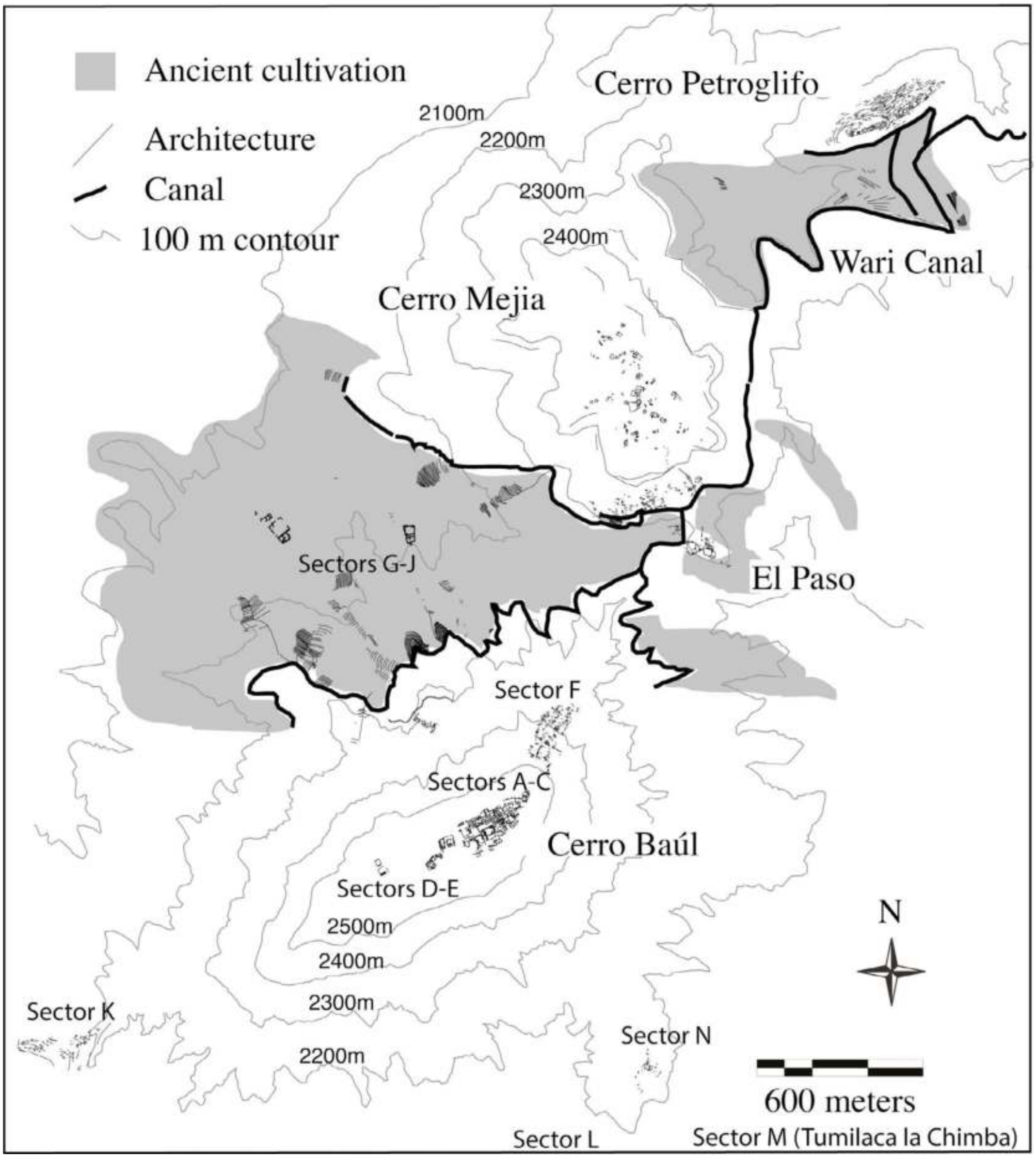

Figure 10.2. Map of the Cerro Baúl colony and environs, highlighting the distinct sectors with differential obsidian presence.

Figure 3, Sector B). Obsidian at Yahuay Alta was found only in the five excavated contexts that dated to the Middle Horizon, four of which are located in the eastern half of the site in relatively close proximity to the platform mound-plaza complex (Costion 2009).

Cerro Baúl and Cerro Mejía

These two sites represent the primary Wari occupations in the Moquegua Valley. Cerro Baúl is located on the summit of a kilometer long mesa that towers in the upper Moquegua valley. Its slopes contain settlements of both Wari and Tiwanaku affiliation. While most obsidian is concentrated in the summit contexts representing elite residence, administrative and religious architecture, and artisan production facilities that are overwhelmingly affiliated with Wari occupation, obsidian does also appear in limited quantities in the surrounding villages and are included in this assemblage. Cerro Mejia is located adjacent to Cerro Baúl and contains intermediate elite architecture on its summit, and smaller households in neighborhoods on its slopes. The obsidian assemblage used here draws on excavations conducted on Cerro Baúl in 1989 by Robert Feldman and excavations by Williams and Nash from 1997–2016 (Williams 2001; Nash 2012, 2017; Nash and Williams 2009, 2021). We also include an assemblage of material sourced by Richard Burger from surface collections at the site (Burger *et al.* 2001).

Cerro Mejia was excavated by Donna Nash between 1999 and 2011, and the dataset here represents sourced material from those excavations on both the summit and slopes of the mountain. The summit of Cerro Mejía is approximately 100 meters below that of Baúl.

Mejía's summit was demarcated by a thick boundary wall, where sheer cliffs were not present, and surmounted via a wide staircase on the southern slope facing Cerro Baúl. The summit has more than fifty large residential compounds, which are spread out rather than agglutinated like those on Baúl. Three of these have been excavated to some degree and contribute to this sample. The slopes were dotted with terraced dwellings that were divided by walls and canyons into several neighborhoods. The sample comes from the excavation of eleven Wari-affiliated houses of different size and construction style (Nash 2017). One house may have been occupied by a specialist who shaped points and other tools because a high concentration of obsidian reduction waste was found in a single small room. All houses at the site had very small obsidian debitage of the type generated by sharpening or edge maintenance (Nash 2012).

Tumilaca la Chimba

Tumilaca la Chimba is a settlement on the slopes of Cerro Baúl that spans the terminal Middle Horizon to the Late Intermediate Period. It is the type site for the Tumilaca archaeological culture, a late Tiwanaku cultural component. First excavated by Romulo Pari (1980) and then the Programa Contisuyo, the dataset analyzed here was excavated by Nicola Sharratt between 2006 and 2016 (Sharratt 2019). The Tumilaca phase (*c.* 950–1250 CE) occupation includes residential structures, four cemeteries, and a non-domestic community structure (Sharratt 2016; Sharratt *et al.* 2012). This occupation is partially covered by a second Estuquiña phase (*c.* 1250–1450 CE) occupation. However, no obsidian was recovered from contexts securely associated with the Estuquiña occupation, with one fragment recovered from a mixed context (Sharratt 2020). Obsidian included in the present study were excavated from five Tumilaca phase residential structures, which varied in size, architectural complexity, and construction quality, as well as from Tumilaca style burials located in two of the cemeteries, and from the community structure.

Capanto, Las Peñas, and Colorado Mogoté

These are small later Late Intermediate Period (1200–1450 CE) sites circumscribed by defensive walls. Capanto and Las Peñas may have been occupied into the Inca Era, whereas the sample from Colorado Mogoté is small and inconclusive in this regard. These three sites were sampled by Nash and Chacaltana in 2012 and extensive excavations at Las Peñas were directed by Nash in 2015 and 2016. Capanto is located near the modern town of Torata, a low hill near the floodplain. The ceramic assemblage from Capanto includes Tumilaca, Estuquiña, Gentilar, San Miguel, and local variations of Inca style wares (see also Bürgi 1993:156). Materials from the other two sites are more modest with few to no decorated vessels and domestic assemblages overlapping with other Estuquiña settlements. They are both located on narrow ridges oriented perpendicular to the Torata river and have small to moderately sized terrace dwellings along the top and west face of the ridge. Las Peñas has a *capilla* with a cross that is celebrated in May every year, although no prehistoric ceremonial feature has been identified at the chapel.

Sabaya, Torata Alta, and Camata

These three sites date to the Late Horizon and Torata Alta was occupied into the early Colonial Period. Sabaya was the Inca provincial capital of the upper Moquegua valley, while Camata was an important local settlement and *tambo* along the Inca road connecting Torata to the Inca centers of the altiplano (Dayton 2008; Chacaltana 2014, 2015). Torata Alta is an early colonial *reducción* in the upper valley, which may also have been occupied during the Inca period. The sites of Sabaya and Camata were excavated by Peter Burgi in the late 1980's (1993), and Torata Alta was likewise excavated by Programa Contisuyo archaeologists at that time (Van Buren 1993; deFrance 1993). The datasets discussed here from Sabaya and Torata Alta were excavated by Sofia Chacaltana in 2013 and from Camata in 2006 (Chacaltana *et al.* 2010).

Tacahuay and Punta Picata

Tacahuay is a Late Intermediate site occupied during the Inca period. It has been suggested it was a coastal enclave from the altiplano settled in order to extract coastal resources via building socio-economic alliances between elites (Chacaltana 2017). During the Inca period this site was part of a complex network of exchange of a variety of materials (ceramics, metal objects, Inca wood vessels or keros, etc); however, according to the excavations it did not include obsidian.

Punta Picata is a Late Intermediate site of a specialized fishing community occupied during the Inca period. It was excavated in 2010 by members of the Program of Investigations Tacahuay Tambo and Punta Picata directed by Alfredo Bar (Bar 2010) (Chacaltana 2015; deFrance and Olson 2013). Excavations at this site did not recover obsidian materials or fragments; nonetheless, it used and was a local quarrying source of *coquina* (maritime grain-stone) (deFrance and Olson 2013).

The Sources of Moquegua Valley Obsidian Through Time

While human settlement in the Moquegua valley dates back over 12,000 years (deFrance *et al.* 2001), our focus is on the permanent, settled agricultural populations that emerged at the beginning of the second millennium BCE, where we have permanent settled villages with long term occupations. Archaic period settlers used obsidian and inhabited temporary settlements throughout the valley, including at Asana, where a dozen obsidian flakes dating to 9000 years ago with at least some from the Chivay source were recovered (Aldenderfer 1998:157, 163). This early use of obsidian in the valley demonstrates that regional networks of obsidian exchange flourished once humans colonized the continent and the region. Our sample begins with Formative settlements dating to several thousand years later, and in concert with the introduction of pottery and settled agricultural villages in the region.

The Late Formative Period (400 BCE–600 CE)

During the Formative Period, small villages thrived along the middle Valley floodplain, farming the immediately adjacent low terraces along the Moquegua River. The upper valley was sparsely populated with few documented settlements at this time. Formative villages may have been organized into irrigation communities along a short irrigation canal that provided a level of supra-village integration (Williams 2020). They maintained sporadic connections with distant societies including Pukara and Nasca (Goldstein 2000), and a few exotic goods arrived into these communities through these connections. Even so, it appears that obsidian was not generally counted among the most valued of these exotic goods during this time.

In fact, obsidian was relatively scarce in Moquegua during the Late Formative period. A total of 10 fragments of obsidian were recovered from Formative sites in the MAS survey from six distinct sites (Table 10.1). No more than two obsidian objects came from any one site (Reid *et al.*, i.p.). The assemblage is dominated by the Chivay source, with 70 % of obsidian, with Alca-1 representing the other 30 %. Chivay is the closest high-quality source to Moquegua. Quispisisa, which becomes important in the following Middle Horizon, is absent from the Formative Period assemblage, and unlikely a sampling issue. As the furthest source from Moquegua and in the vicinity of Wari's heartland, it apparently only appears with later Wari expansion. Even so, given that these are surface finds, it is possible that these obsidian objects were deposited on the sites after their abandonment, perhaps by Middle Horizon folks who utilized obsidian much more extensively. The excavations in the Formative contexts at Yahuay Alta are telling in this regard. No obsidian was recovered from the Formative components at Yahuay Alta, despite employing the same excavation methodology as in the Middle Horizon contexts at the site where a substantial assemblage was recovered (Costion 2009; Green and Costion 2017).

Across the continental divide and in the high plains beyond the Moquegua Valley, the cave site of Quillqatani indicated that Formative period pastoralists in the high plains utilized a higher percentage of obsidian in the lithic assemblage than prior and subsequent occupants of the small rock shelter (Aldenderfer 1999). The pattern of obsidian paucity that we document was not necessarily a generalized pattern, but one that characterized the agrarian communities of the Pacific watershed valleys in the South-Central Andes. It is significant that obsidian was present among these agriculturists, but in low levels that indicate it was not a primary commodity for these communities.

The Middle Horizon (600–1000 CE)

The Middle Horizon saw the most widespread use of obsidian in the history of Moquegua. Driven principally by obsidian consumption at Cerro Baúl and the sites with which it interacted, obsidian use was pronounced at sites affiliated with Wari influence. In terms of raw numbers, Cerro Baúl, and to a lesser extent Cerro Mejia, dominate the assemblage of sourced obsidian in the valley. Of the 615 obsidian objects in this analysis, over half come from Cerro Baúl and nearly one quarter from Cerro Mejia. At these two sites, Alca-1 obsidian predominates the assemblage, representing nearly 80% of the sourced assemblage at Baúl and over 50% at Cerro Mejia. Quispisisa obsidian represents 14% of the sourced assemblage at Baúl and 34% at Mejia.

In the Middle Valley Middle Horizon sites, associated with Tiwanaku contexts, obsidian was relatively rare, as Tiwanaku settlers used other materials for most lithics. A total of only 48 obsidian objects were found in Tiwanaku contexts and all were sourced (Reid *et al.* i.p.). Here, only 35% of the obsidian is Alca-1, with Quispisisa only competing with many other sources for second place, including Alca-5/Charaña, Anillo, Chivay, and Potreropampa. This pattern is replicated at the terminal Tiwanaku site of Tumilaca la Chimba on the slopes of Cerro Baúl, where 46 sourced objects were composed of 41% Alca-1, with Chivay, Quispisisa, and Potreropampa each accounting for 15–24% of the assemblage.

The site of Yahuay Alta provides an interesting contrast to the Tiwanaku source assemblage, despite being in the Middle Valley. Here, nearly 80% of the assemblage of 24 sourced obsidian objects is Alca-1, while Chivay and Quispisisa represent around 10% of the assemblage each. This assemblage makeup strongly parallels the assemblage at Cerro Baúl and suggests that Yahuay residents likely obtained most of their obsidian through the Cerro Baúl obsidian network, rather than through the more diverse and meager obsidian network that supplied Tiwanaku settlements.

One explanation for Yahuay's dependence on Baúl obsidian is that it is located along the likely road between Cerro Baúl and the Wari realms further north (Williams, i.p.). This same road likely passed through the nearby settlement of Cerro Trapiche, which also contained a Wari style brewery (Green and Goldstein 2009). The small sample of obsidian (n=5) sourced from the Trapiche site as part of the Mid Valley Middle Horizon assemblage was 100% Alca-1.

Thus, there appear to be two distinct obsidian exchange networks in place in Moquegua during the Middle Horizon. The most prolific of these was the Wari obsidian network, focused on Alca-1 and to a lesser extent Quispisisa. Quispisisa may have been more important earlier in the Wari expansion and was outpaced by Alca-1 obsidian later in time (Williams *et al.* 2012: 84). This exchange system supplied the site of Cerro Baúl with an overwhelming proportion of the sourced assemblage in this network. We hypothesize that from Baúl, obsidian was distributed to clients and allies at sites like Cerro Mejia and Yahuay Alta, and perhaps Cerro Trapiche. Some of this obsidian may also have found its way to Tumilaca la Chimba through secondary exchange or scavenging after Wari actors left. And some of it inevitably made its way into the Tiwanaku sites of the Middle Valley.

The second network was a more diffuse, less centralized network of obsidian exchange that brought some obsidian to the Tiwanaku settlements in the valley. Alca-1 was still a part of this network, but it did not supply the majority of obsidian to these settlements. Alca-1 still represents a plurality of obsidian used by the Tiwanaku groups, and it was likely obtained through informal exchange with the Wari network. Other smaller sources, often closer to Moquegua, are also well represented. The Charaña source, located in the highlands of nearby Tarapaca, is one of the lower quality sources represented in the assemblage (Burger *et al.* 2021). It can be easily confused chemically with Alca-5 when measured with p-XRF, which is why we list it here as Alca-5/ Charaña. Chivay, the closest high-quality source of obsidian and a favored source for the Tiwanaku heartland, is also represented, but in relatively small numbers compared to its prevalence in the Formative.

Chivay is also represented in small quantities at Cerro Baúl and Cerro Mejia, and it is instructive to observe where Chivay obsidian is found in those settlements. At Baúl, for example, nearly half of the excavated Chivay objects come from one room of the Tiwanaku temple on the summit of the great mesa (Williams and Nash 2016). Excavations conducted after the 2016 publication recovered nine obsidian points, six of which were sourced to the Chivay source and three to Alca-1, from that context. Meanwhile, one-third of Cerro Baúl's excavated assemblage of Chivay obsidian is from the settlements on the slopes of Cerro Baúl that were primarily populated by Tiwanaku villages dedicated to farming Wari fields in the latter half of the Middle Horizon. Fewer than five Chivay objects come from actual Wari excavated contexts of the more than 250 sourced objects from excavations in this analysis.

Late Intermediate Period (1000–1400 CE)

After the fall of Wari and Tiwanaku, the Moquegua valley obsidian networks collapsed. The site of Tumilaca la Chimba represents the last persistent use of obsidian in a prehispanic settlement in the Moquegua valley, and even this material is relatively scarce, perhaps having been scavenged from Wari settlements after abandonment. The Tumilaca component of this settlement persisted until at least 1250 CE (Sharratt 2019), and it is this component that represents the sourced obsidian assemblage for the site. After 1250 CE, the settlement largely shifted to the northern edge of the site and upslope to the summit of the hill on which it was situated. These contexts are bereft of obsidian and even lacked scavenged objects from the older settlement.

The MAS survey recovered only one object sourced to Alca-1 from the Mid valley associated with the LIP. The middle valley was populated by dozens of archaeological sites during this period, but obsidian use was virtually absent from surface collections (Goldstein 2005). Furthermore, excavations of settlements in the upper valley also reveal a complete absence of obsidian from excavated contexts of late LIP settlements. The sites of Colorado Mogoté, Capanto, and Las Peñas excavated by Nash yielded no obsidian in extensive excavations. They all date to the latter half of the Late Intermediate period.

Late Horizon (1400–1532 CE)

Despite the conquest by the Inca empire in the 15th century CE, the valley did not experience a new boom in obsidian exchange. Excavations by Chacaltana at the Inca administrative capital of Sabaya and the Inka/ early Colonial reduccíon of Torata Alta recovered only three obsidian objects (they have not been sourced). Excavations at Camata Pueblo (LIP) and Camata Tambo (Inca) by Barrionuevo, Chacaltana, and Dayton recovered no obsidian material in the assemblage. Excavations at the site of Tacahuay Tambo and Punta Picata on the Pacific coast south of the Moquegua valley by Chacaltana and deFrance recovered only one obsidian object in the entire lithic assemblage. While obsidian tools were more ubiquitous in Inca contexts elsewhere in the empire, the Moquegua valley did not experience an "age of obsidian" as it did during the Middle Horizon when the Wari held sway.

The sourced obsidian material provides a perspective on the use of different source material through time. In order to assess the dynamics of obsidian movement between settlements in the different time periods, we now turn to an analysis of the prevalence of obsidian in the sites where is it most pronounced: several of the Middle Horizon settlements on and around Cerro Baúl and the middle valley where comparable data is available. We examine average weight of obsidian implements, density of obsidian material, and ubiquity of obsidian within several large collections of lithic material from different sectors at Cerros Baúl and Mejia, Yahuay Alta, and Tumilaca la Chimba.

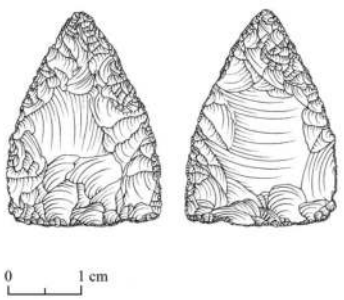

Figure 10.3. Reworked laurel leaf obsidian point CB01-3682 sourced to Alca-1 and recovered from the Sector A Palace complex 9B-B on Cerro Baúl (drawing by J. Seagard).

Modeling Obsidian Use: Average weight, Density, and Ubiquity

Obsidian average weight is probably not a metric of great utility in assessing obsidian prevalence at a site. Unprocessed large nodules would tend to have higher average obsidian weights, while small pressure flakes in the absence of their cores would tend to have lower average weights. Thus, some major differences in obsidian scarcity or stages of production may be reflected in average weights. However, any obsidian use context where implements are accompanied by sharpening by flaking would tend to result in bimodal distributions of obsidian weight and be of little utility.

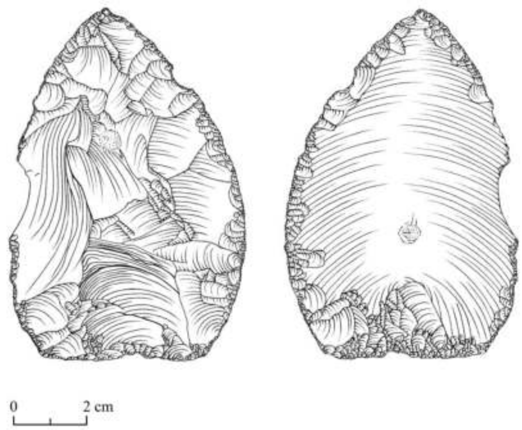

Figure 10.4. Obsidian pre-form CB07-41-0384 sourced to Alca-1 and recovered from the Sector A Palace Complex 41A-D2 on Cerro Baúl (drawing by J. Seagard).

There are some interesting patterns in the average obsidian piece weight in the data from the 2002 excavations at Cerro Baúl (Figure 10.2). In sectors A, C, and K, obsidian average weights range from 0.5g to 2.2g per fragment (Table 10.2). If we remove pressure flakes under 0.2g in weight from the equation, implement average weights vary from 1.5g to 2.7g in these assemblages (Figures 10.3–5). Compared to the average obsidian weights from the Tiwanaku related contexts in sector excavations (F, G, H, I, and N), these average weights are substantially greater than those from Tiwanaku houses on the slopes of the mesa. In these sectors, average weights are around 0.2g per fragment regardless of whether we remove the smaller pressure flakes from the sample.

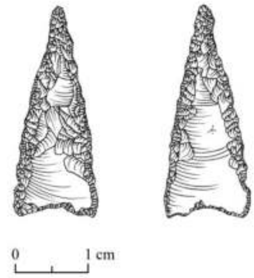

Figure 10.5. Obsidian drill CB02-09-1149 sourced to Alca-1 and recovered from the Sector A Palace Complex 9G-B on Cerro Baúl (drawing by J. Seagard).

For Cerro Mejia's excavated context based on Nash's excavations in 2000, 2008, 2009, and 2011, average weights of obsidian objects were 0.10g in houses on the slopes of the mountain while summit residences and workshops of the intermediate elite had an average obsidian piece weight of 0.18g. This means that obsidian pieces on Mejia were 5 to 10 times smaller than on Cerro Baúl by weight. And Mejia summit obsidian was on average twice the size of obsidian from houses on the slopes. The smaller size in slope houses may reflect that these less wealthy households practiced more reduction and worked with smaller and smaller fragments than their wealthier counterparts. They may also have produced more retouch flakes and sharpened obsidian more than their more prosperous neighbors.

Meanwhile at the Middle Horizon contexts at Yahuay Alta, average weight of an obsidian implement was 0.79g, approaching the range of average weight for the Cerro Baúl pieces. It is possible that this site has retouch flakes and small fragments under-represented, but it nevertheless falls within the range of average implement weight. Thus, we can say that in Wari contexts at Cerro Baúl and Mejia, and perhaps at Yahuay Alta, there is a mixed set of implements and flakes from sharpening and working the material. Meanwhile, the Tiwanaku contexts around Baúl are characterized by smaller fragments of obsidian and are generally lacking larger implements weighing upwards of 1g. This systematic collection of obsidian, which is not reliant on minimum obsidian size that is present in the sourcing study materials, provides some insight into the differential use of obsidian in the distinct contexts.

We do note that the average weight of obsidian from Tumilaca la Chimba is 0.71g per implement. This includes the obsidian that was too small for sourcing from the Tumilaca phase contexts. These contexts date to the end of Wari influence in the Middle Horizon and a couple centuries after the departure of Wari state officials. Tumilaca la Chimba residents continued occupying their area until approximately 1250 CE, and their use of obsidian includes periods when Wari exchange networks were active as well as after the presumed collapse of those networks. Tumilaca residents would likely have had access to material scavenged from Wari sites after the departure of the Wari dwellers and the abandonment of their settlements on Cerro Baúl and Cerro Mejia.

Obsidian density per excavated site area may be a more indicative measure of obsidian presence. At Cerro Baúl, obsidian weight per square meter excavated ranged from 1.17g to 2.47g in contexts on the summit of the mesa (Table 10.2). Sector K, the site with elite Wari pottery on the western slope, was close behind with 0.65g per square meter. Moving further downstream, Yahuay Alta's Middle Horizon contexts had 0.19g of obsidian recovered per square meter excavated. At Cerro Mejia, just upstream from Baúl, weights per square meter excavated ranged from 0.21g on the slopes to 0.24g on the summit. Meanwhile, obsidian densities for Tiwanaku related contexts on the slopes of Cerro Baúl ranged from .01g in sectors F, G, H, and I to 0.02g in sector N and 0.2 g in sector L. These latter examples fall clearly on the lower end of obsidian densities despite their proximity to the Cerro Baúl summit. They are decidedly residential contexts with a non-Wari, Tiwanaku identity based on ceramics present. At Tumilaca la Chimba, weights per meter square are 0.23g, closer to the Mejia and Yahuay Alta numbers, though radiocarbon dates for Tumilaca Phase La Chimba are later than those sites and may represent increased access from scavenging after Wari abandonment.

Obsidian counts per square meter, another measure of density, can be highly influenced by reduction strategies and use, as well as the type of material (retouch flakes, large implements) present at the site. Still, we note that counts per square meter on Cerro Baúl range from 1 to 1.2 implements and counts per square meter on Cerro Mejia range from 1.3 to 2.1 pieces per square meter. Meanwhile, Yahuay Alta had 0.24 obsidian objects per square meter, and the Tiwanaku contexts on the slopes of Cerro Baúl ranged from 0.03 to 0.09 obsidian fragments per meter square excavated. At Tumilaca la Chimba, counts were closer to Yahuay Alta with 0.33 fragments per square meter.

Both these measures of obsidian density, weight per square meter and count per square meter, indicate that the summit contexts on Cerro Baúl had the highest measures of obsidian presence in the contemporary settlements examined. And the lowest measures of obsidian density were in the Tiwanaku related residential contexts on the slopes of the mountain. Comparative data from Tiwanaku settlements downstream should be similar to those from the slopes of Cerro Baúl.

Ubiquity measures for obsidian vary substantially by site as well and are perhaps more indicative of the commonality of use of obsidian at a site. Ubiquity controls for the size of excavation as well as diminishes the importance of singular large caches or pieces of material, and thus is more reflective of the spatial spread of obsidian use in any particular context. At Cerro Baúl during the 2002 excavation season, obsidian was present in 47% of the square meter excavation units in sector A, the palace and artisan residence area (Table 10.2). It was present in 55% of the meter squares in sector C, the D-shaped temple annex. At the Wari residential site of Pampa del Arrastrado (sector K), it was present in 62% of the excavation square meter units. At Cerro Mejia, obsidian was present in 36% of the meter squares in houses on the slopes of the mountain. Elite residences and workshops on the summit of the mountain had obsidian present in 26% of the meter squares excavated. Mejia summit residences were much more ample in their spacing and had the capacity to dedicate certain areas for obsidian use, whereas slope residences were much smaller, as they were at Pampa de Arrastrado, and thus floor areas were more often multi-craft spaces.

Meanwhile, in the excavations in the primarily Tiwanaku related sectors N and L (El Tenedor and Santa Rita in the Tumilaca valley side of Cerro Baúl), it was present in only 7% and 4% of the excavation square meter units, respectively. Yahuay Alta had a ubiquity of 10% based on Costion's excavations at the site (Table 10.2). At Tumilaca la Chimba, Sharratt documented a ubiquity measure of 21% in the Tumilaca Phase contexts, while it was only 0.4% in the later Estuquiña phase contexts.

The obsidian average weight, density, and ubiquity data indicate that the summit of Cerro Baúl was the locale with the largest obsidian objects, with the highest density by count and weight of obsidian material and the greatest ubiquity of obsidian in all the sites sampled. The smallest pieces of obsidian, with lowest density and lowest ubiquity were located in the Tiwanaku related sectors on the slopes of Cerro Baúl, with the exception of Tumilaca la Chimba, which may partially reflect increased access in the waning days of Wari influence. Other Wari influenced settlements fell between these measures. Cerro Mejia had low average implement weights, but higher average counts per square meter. Ubiquity, however, was lower overall, though not as low as the Tiwanaku cases. At Yahuay Alta, average implement weight was higher than at Mejia, but obsidian density by count and weight was lower. This might suggest obsidian reduction was more pronounced at Mejia than elsewhere, reflecting intensive use of the material. Pampa del Arrastrado (Sector K), meanwhile, had the highest ubiquity for obsidian, and high density by count of the sites sampled. Density by weight and average weight of obsidian objects were somewhat lower than the summit contexts on Cerro Baúl. It is closest to Cerro Baúl in terms of the obsidian assemblage present, though the objects are roughly half the size as those on the summit.

Given these patterns, Cerro Baúl appears to be the locale where obsidian accumulated through Wari import networks to the valley. The largest objects and the density and ubiquity are highest at this site and its sector K outpost. We hypothesize that closely affiliated settlers at sites like Cerro Mejia and Yahuay Alta likely received obsidian directly from Cerro Baúl in a down the line exchange from their close political ally. Meanwhile settlements further removed from the Cerro Baúl interaction sphere likely obtained obsidian from low-level exchange with Wari allies or from scavenging abandoned Wari settlements for small pieces of obsidian. It is possible that some Tiwanaku settlements like Tumilaca la Chimba may have obtained obsidian directly from Cerro Baúl as close political allies despite their use of Tiwanaku pottery and domestic practice.

Obsidian weight, ubiquity, and average weight and counts per meter excavated are all virtually nil for the Late Intermediate Period and the Late Horizon, despite extensive excavations at sites from these periods. Nash, for example, found no obsidian in excavations at Colorado Mogote, Las Peñas, or Capanto, despite excavations exceeding 1000 square meters in house structures. Sharratt's excavations at Tumilaca la Chimba were roughly split between Tumilaca phase contexts (950–1250 CE) and Estuquiña phase contexts (1250–1450 CE). Yet the latter context only had one small piece of obsidian recorded in surface levels. The pattern is similar for Late Horizon sites excavated by Chacaltana, where hundreds of square meters of excavation at Tambo Tacahuay and Punta Picata on the Pacific coast recovered only one obsidian implement. Excavations in the highland sites of Camata, Sabaya, and Torata Alta in the immediate environs of Cerro Baúl recovered 3 obsidian implements. These pale in comparison to the prevalence of obsidian in the Middle Horizon Wari sphere.

Discussion and Conclusions

Obsidian represents a material commodity that relied on state networks for distribution during the Middle Horizon. Unlike ceramics, which were not widely imported (Williams *et al.* 2019) by the Wari or Tiwanaku states, obsidian played a significant role in Wari distribution networks, although it remained a rarity in Tiwanaku sites. Archaeologists often rely heavily on ceramic distributions in assessing political hegemony, but in this case, obsidian from the Alca-1 and Quispisisa sources is one of the best proxies for participation in Wari exchange networks of the Middle Horizon in Moquegua. Interestingly, obsidian is not an effective proxy for assessment of participation in state exchange networks during the Inca period.

One interesting note is that obsidian, which became such an important commodity during the Middle Horizon, was more accessible to Wari allies than to Tiwanaku peoples. Tiwanaku tended to have access to far less obsidian material, but obsidian from more diverse sources. Much of the more diverse source material came from smaller sources closer to the use context, as opposed to the more distant sources like Quispisisa or Alca-1. There also may be more continuity in small scale obsidian use between the Formative period, when it was used at low levels, and the non-Wari networks of the Middle Horizon, where white chert and other lower quality materials, such as dacite and rhyolite, dominate the lithic assemblage.

After the end of the Wari and Tiwanaku states, obsidian use drops out of the regional exchange systems almost entirely, perhaps due to a breakdown in long distance procurement networks. This mirrors a general decrease in the complexity and intensity of regional cross-cultural interactions during this time period (Costion and Green 2018). Even so, regional sources like Charaña or Chivay are no longer in use in the LIP either. Perhaps with the drop in the use of obsidian overall with the loss of the Wari and Tiwanaku state networks, demand for obsidian as a commodity in general fell off entirely. Even the relatively poor quality local and regional sources were no longer worth pursuing. Obsidian was a ritually charged and symbolic item in Middle Horizon networks and used in cache offerings for ritual payments to mountain deities, linked to ensure continued supplies of water resources in addition to other benefits (Glowacki and Malpass 2003). Perhaps a collapse of the association of obsidian with ritual offerings as well as a collapse of high quality obsidian networks accounted for the complete drop-off in the use of obsidian.

The Late Horizon did not replicate the demand for obsidian that was seen during the Middle Horizon. While access increased slightly since the Late Intermediate Period, obsidian was neither ubiquitous nor extensively used as it had been during the second half of the first millennium CE. This is certainly not the case across the Andes; the Inca occupations of highland Ecuador extensively exploited regional obsidian sources for implements on an actively contested frontier (Ogburn *et al.* 2009). However, the extent of obsidian use varied greatly across the Inca empire. Anecdotally, it does appear that Wari obsidian was much more accessible and ubiquitous in use at Wari and Wari influenced settlements across the Andes, and especially in other regions in the southern highlands (see Reid *et al.*, this volume).

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Chapter 11

Concluding Thoughts: Open Networks, Economic Transfers, and Sourcing Obsidian

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Abstract

We are at a juncture when the comparative investigation of humanity's past has led to recognition that human cooperative arrangements tended to be neither closed nor tightly bounded and that the links between human institutions, affiliated groups, and communities were as important for understanding as were the scale and organization of those nodes themselves. And yet, visioning the movement of humans, their goods, and information always has been a challenge for studying the past, especially when investigations are heavily reliant on archaeological information. Despite these challenges, archaeologists are broadening their perspective on past human networks and the goods that were transferred through them. The application of new compositional analytical techniques, especially as implemented on obsidian, have fostered these efforts, providing a more fulsome empirical record. Advances in research carried out at the Elemental Analysis Facility at the Field Museum of Natural History are featured here with a focus on those investigatory efforts situated in the precolonial Americas.

Obsidian has long garnered the attention of archaeological investigators. Shiny, translucent, and sharp, crafted skillfully in striking ways, objects of volcanic glass have been a staple of museum displays and archaeological investigations for more than a century. Discoveries that allowed us to define the composition of different obsidians, and thereby identify their outcrops and sources, only magnified the archaeological importance of this raw material and its products (Dixon *et al.* 1968). Now, as the technologies that can be employed to define the elemental composition of obsidian have become less costly, more portable, and less destructive, the significance of this glassy material for helping elucidate the shifting social networks and economic transfers that characterize humanity's past is even further intensified.

In the Americas, the rise of archaeology as an academic pursuit during the late nineteenth century coincided with conceptual framing that placed a heavy dependence on long-distance processes, such as migration and diffusion (e.g., Wissler 1923). At that time, the cultural history approach also was adopted, inspired by Linnaean biological constructs, to categorize and organize the expanding corpus of archaeological data (Feinman and Neitzel 2020). Over the next century or so, as the pace of field investigation expanded, culture historical units were refined into narrower spatial referents. The more localized, descriptive focus of mid-twentieth century culture history coincided with broader social science trends that emphasized developmentalist frameworks (e.g., Rostow 1960), which largely were grounded in endogenous change and post-war treaties that fostered the notion that national borders and identities were relatively stable, concretized over time. Ironically, the growing potential to employ the composition of obsidians to document and define long-distance economic transfers during the 1960s came at just the time when homeostatic assumptions about human social networks and quaint biases toward localism and self-sufficiency were at their height.

Developmental and neo-evolutionary frames that underpinned mid-twentieth anthropological archaeology likewise were grounded in rather linear models of change, such as Service's (1962) band-tribe-chiefdom-state and Sahlins' (1972) sequence of economic transfers: reciprocity, redistribution, and market exchange (see also Polanyi 1944). These Cold War-era schema tended to presume that premodern polities, such as chiefdoms and states, were almost exclusively autocratically governed with state control of production and reliance on redistributive modes of economic transfer. When exchange was probed, somewhat artificial distinctions were drawn between external and internal trade (e.g., Webb 1974).

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Over the last five decades, archaeological knowledge and the volume of data have exploded. The greater breadth and depth of archaeological findings have cast serious empirical doubt on notions of uniform or linear sequences of change, culture historical assumptions regarding the closure and homogeneity of human groupings, as well as presumptions that the political economies of premodern polities were despotic and centrally controlled (e.g., Blanton and Fargher 2008; Feinman 2017; Feinman and Neitzel 2020). As evidence mounted, by the 1970s–1980s, key academic figures pushed back on the mid-century dogmas. Robert McC. Adams (1974) questioned Polanyi's (1944) anti-market and central control biases in regard to pre-modern economies, while Eric R. Wolf (1982) established the persistent openness of most human social and cooperative networks, even in the precolonial Americas where transport options generally were limited. In response to (and building on) Immanuel Wallerstein's (1979) macroregional frame, the case was made for long-distance economic interdependences in premodern American worlds (Blanton and Feinman 1984). More recently, it has become evident that material cultural and political boundaries do not necessarily align (Feinman and Neitzel 2020; Feinman and Nicholas 2017; Smith 2005), while patterns of economic access and activity can vary at any scale from the domestic unit to the settlement to regions. The homogeneities in access, consumption, and practice within units that often were presumed by cultural historical constructs (such as the notion of type-site) and manifested in assumptions of yore regularly have not been documented or confirmed when suitable volumes of archaeological data were amassed.

Human systems, both political and economic, small and large, are in general somewhat open and also complex (Adams 1977; Foley and Gamble 2009; Rebout *et al.* 2021), if the latter is defined as the ability to produce uncertainty or unpredictable outcomes. The degree of complexity is a product of the number of component units, the diversity of those units, and the ways the units are connected (Rebout *et al.* 2021). So, human networks are complex, but some are larger, more diverse, and intricately interconnected than others (e.g., Blanton *et al.* 1993). Nevertheless, from this perspective, it is equally critical to define and understand the size or scale of human networks and groupings, but also the nature of their connectivity. Humans and their institutions do not necessarily articulate in uniform ways (Feinman 2021; Kowalewski and Birch 2020). And, as noted above, how human social formations were configured was not exclusively top-down or predicated by scale, nor uniform or regular across time or space.

Given the clear limitations of linear, categorical thinking when it comes to human history, patterns of human connectedness and how they shifted over time must be empirically assessed rather than presumed. Ancient DNA and isotopic analyses provide insights into the patterns and paths of human movement (e.g., Furholt 2021; Mittnik *et al.* 2019), but what about the volume, directionality, and modes of transfer for human goods? Archaeologists have entrenched means to examine trade and exchange, but, for the most part, they have relied on small quantities of clearly exotic materials to illustrate the existence of long-distance links.

Much of the early sourcing research on obsidian contributed to these findings, the use of small obsidian samples to document the presence-absence of contacts between known outcrops and sources and the nodes or settlements where this material was consumed and used. Compositional analysis, using techniques like neutron activation and mass spectrometry, opened investigatory portals that served to define unique elemental signatures for different obsidian outcrops. As a result, source definitions were possible for limited samples of obsidian derived from archaeological research. Yet, these destructive and relatively expensive technologies limited the sample sizes that could be examined from specific archaeological contexts, thereby restricting interpretations to presence-absence and at times, the basic proportional rankings between those sources present in specific loci or context.

More recently, and underpinned by the prior research on compositional signatures for many obsidian sources, the increasing utilization of portable X-ray fluorescence has revolutionized the efforts of archaeologists to define and document past shifts in the transfer of this key good (e.g., Golitko 2019). The four key attributes of this mode of instrumentation (portability, non-destructive, inexpensive, and speed) greatly enhance what we are able to learn regarding trade and exchange.

In this volume, the chapter by Danielle Riebe and colleagues (chapter 2) illustrates how non-destructive technologies (pXRF, XRF, and short irradiation NAA) allow for multiple measurements of rare obsidian artifacts that were recovered in Lake Huron. Through a research strategy that jointly employed a suite of instrumentations, the authors were able to document that obsidian was transferred west–east across the North American continent at an early date. The non-destructive and cost advantages of pXRF also are evidenced in the Hopewell study, enacted by Mark Golitko and colleagues (chapter 3). In that work, the ability of the authors to analyze the elemental composition of a sizeable sample of the obsidian artifacts from this key context allow them finally to dismiss the long-held, old canard that all the Hopewell obsidian could have arrived from the west to Ohio in one trip! The capability to examine significant samples of relatively well-contextualized obsidian also permitted Danielle Riebe and co-authors (chapter 4) to note shifts in procurement with increasingly more sedentary settlements during the Archaic period in the American Southwest. The opportunity to analyze a sizeable number of tiny debitage samples of obsidian, which may have been destroyed if subjected to other compositional analytical instrumentation, contributed to David Reid and colleagues' (chapter 9) efforts to define caravan routes and paths over which Andean obsidians traveled.

From the single site to the region and at more macroregional scales, the great advantages of large sample sizes and more holistic analyses have refined and expanded the kinds of research questions asked. Focused on the Classic Maya urban settlement of Tikal in Guatemala, Moholy-Nagy (chapter 6) was able to demonstrate that different artifact classes tended to be made using different obsidian sources, yielding insights into where those objects may have been made. Bernadette Cap (chapter 7) also draws her obsidian from a single archaeological site, Buenavista del Cayo. But again, through the examination of large obsidian samples, Cap is able to determine that some obsidian tools were made near the site's marketplace.

Likewise, for larger-scale analytical vantages, the advantages of large sample sizes made possible with pXRF were leveraged through the collaborative pooling of data by teams of investigators. These cooperative endeavors permit the quantitative documentation of shifting exchange relations across regions, such as in Moquegua, Peru (Ryan Williams and colleagues, chapter 10), and the Valley of Oaxaca, Mexico (Linda Nicholas and colleagues, chapter 5). In Moquegua, the importance of obsidian was shown to be an economic consequence of the region's links to the Wari empire, such that the abundance of obsidian decreased markedly in quantity once the Wari ties were severed. In Oaxaca, Mexico, the temporal and spatial variations in regional obsidian consumption were far greater than was expected, and importantly, the findings cast great doubt on entrenched notions that the most proximate outcrops of obsidian generally would be most intensely exploited as well as any lingering prospect that redistributive mechanisms might account for the distribution of an exotic good (obsidian).

In a final chapter (chapter 8), by the first author of this work (and colleagues), the analytical scale is raised to prehispanic Mesoamerica as a whole, employing a sample of hundreds of thousands of sourced artifacts of obsidian. The documented variation over time and across space was a stunning finding that illustrates that even in this world with limited long-distance transport options, goods were moved long-distances in quantities, but the specific links forged and paths taken were anything but static (see also Golitko and Feinman 2015).

Another thread that connects many of the chapters in this volume is that they collectively illustrate the importance of well-curated legacy collections and synergies created between the application of new technologies to these long-held obsidian samples and other collections derived and sourced based on new research. Golitko and colleagues (chapter 2), Riebe and co-authors (chapter 4), and Feinman and colleagues (chapter 8) all studied and incorporated legacy collections from the Field Museum of Natural History, some housed there for more than a century, as foundations for research programs that included either the implementation of fieldwork or new syntheses of already published and sourced obsidian data. In tandem, these procedures were employed to build an expanded analytical archive. In parallel, Nicholas and colleagues (chapter 5) Moholy-Nagy (chapter 6), Cap (chapter 7), and Williams and co-authors (chapter 10) all draw on and source collections held in institutional storage facilities across the contemporary Latin American world. The availability of these legacy collections for current research was a key factor that allowed these studies to probe sufficiently large samples to outline key elements of spatial and temporal variation and, most notably, address new dimensions of temporal variation and change within their study regions.

For the precolonial Americas, obsidian was only one of the goods that was valued and so moved great distances. And, although we recognize that whatever patterns we see for obsidian may not necessarily coincide with other commodities, what we now can observe with more quantitatively robust samples of obsidian warn us that human networks were far more open, less local, and more temporally and spatially variable than would have been envisioned decades ago; these new realities must be foundational as we launch and continue future investigations of humanity's career and cooperative arrangements, networks, and ties that were central to it.

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