DETERMINING THE GEOLOGICAL PROVENANCE OF OBSIDIAN ARTIFACTS FROM THE MAYA REGION: A TEST OF THE EFFICACY OF VISUAL SOURCING

Geoffrey E. Braswell, John E. Clark, Kazuo Aoyama, Heather I. McKillop, and Michael D. Glascock

During the last four decades, mesoamerican archaeologists regularly have employed various chemical assay techniques to determine the geological sources of obsidian artifacts. In recent years, the reliability of these analytical procedures has increased and their costs have declined, encouraging the assay of ever larger samples. Nonetheless, several constraints make it unlikely that compositional data will be used routinely to attribute entire collections to their geological sources. This report describes a test of visual sourcing, a technique that for many sites in the Maya region is only slightly less accurate than compositional assay. We also propose sampling strategies that combine visual and compositional sourcing in ways that allow large collections to be accurately sourced at low costs. Finally, we suggest ways to develop the technique for use throughout Latin America.

Durante las últimas décadas, arqueólogos mesoamericanos por lo general han empleado diversas técnicas químicas de análisis para determinar las fuentes geológicas de artefactos de obsidiana. En años recientes, se ha incrementado la confiabilidad de esta clase de procedimientos analíticos en tanto que su costo ha disminuido, de manera que se ha impulsado el análisis de muestras más grandes. No obstante, hay limitantes que vuelven poco probable que los datos composicionales se empleen en forma rutinaria para la atribución de colecciones completas a las fuentes geológicas de origen. En este reporte se describe una prueba del método visual de atribución, que es una técnica ligeramente menos precisa que los análsis composicionales en el caso de muchos sitios en la región maya. Además, proponemos estrategias de muestreo que combinan el método visual con los análisis composicionales, de manera que sea posible definir la fuente geológica de colecciones grandes a un bajo costo. Por último, proponemos medidas para desarrollar el uso de la técnica en toda Latinoamérica.

More than a decade ago, Torrence (1986:10–37) ably summarized the most important studies of long-distance and interregional obsidian exchange in Mesoamerica (e.g., Hammond 1972, 1976; Pires-Ferreira 1975, 1976; Sidrys 1976a, 1976b, 1977). The goal of many researchers at that time was to reconstruct ancient trade routes using geological provenance data gleaned from the chemical assay of obsidian artifacts. More recently, numerous authors have criticized or refined these trade-route models (e.g., Dreiss 1988; Dreiss and Brown 1989, 1991; McKillop et al. 1988). Others have proposed new, detailed hypotheses to replace older, more general conjectures about ancient exchange (e.g., Aoyama 1994; Arnauld 1990; Clark et al. 1989; Clark and Salcedo 1989; Nelson 1980, 1985, 1989). But most research still emphasizes the gathering of source-attribution data rather than the analysis of exchange mechanisms (but see Braswell 1996; Clark and Salcedo 1989; Healan 1993; Zeitlin 1982), and provenance data rarely have been used to formulate and test hypotheses that focus on issues other than trade patterns.

Although there were several early attempts to make source attributions for Maya obsidian artifacts using compositional data (e.g., Washington 1921), chemical analysis became a viable archaeometric technique only 35 years ago (Heizer et al. 1965; Jack

Geoffrey E. Braswell ▪ Department of Anthropology, State University of New York at Buffalo, Amherst, NY 14261
John E. Clark ▪ Department of Anthropology, 950 SWKT, Brigham Young University, Provo, UT 84602
Kazuo Aoyama ▪ Faculty of Humanities, Ibaraki University, Bunkyo 2-1- 1, Mito, Ibaraki 310-8512, Japan
Heather I. McKillop ▪ Department of Geography and Anthropology, Louisiana State University, Baton Rouge, LA 70803
Michael D. Glascock ▪ Research Reactor Center, University of Missouri, Columbia, MO 65211

Latin American Antiquity, 11(3), 2000, pp. 269–282

https://doi.org/10.2307/972178 Published online by Cambridge University Press

and Heizer 1968; Stross et al. 1968; Weaver and Stross 1965). Since then, numerous compositional methods have been employed to make source attributions, but X-ray fluorescence (XRF) and neutron activation analysis (NAA) have emerged as the most common laboratory techniques used to determine the elemental composition, and hence, geologic origin, of obsidian artifacts.

NAA and XRF have become highly accurate techniques, though some source attributions for Mesoamerican artifacts determined before the 1980s almost certainly are erroneous (Glascock et al. 1998:20–22). Recent improvements are due to the rigorous use of standards, a clearer understanding of both intersource and intrasource chemical variation, the determination of concentrations for more elements, and the use of improved statistical techniques to interpret compositional data (Asaro et al. 1978; Glascock et al. 1998; Hughes 1984; Stross et al. 1983). In addition, the federal funding of research reactors and other facilities has allowed laboratory scientists to offer their analytical services at reduced costs. Together, these factors have made the chemical sourcing of Maya obsidian artifacts common.

Nevertheless, it is unlikely that NAA, XRF, or other methods of compositional assay ever will be used routinely to source large samples or entire collections of Mesoamerican obsidian artifacts. Most governments allow only a small fraction of any archaeological collection to leave the country for analysis, and these techniques require expensive equipment that is not commonly available in Latin America. In addition, because of the enormous overhead required to run a research reactor or other facility, even a modest charge for each artifact prohibits the sourcing of more than a few hundred pieces. Finally, NAA and high-precision XRF require that a portion of an artifact be cut, ground, and prepared according to certain standards. In some cases, samples are irradiated and must be disposed of according to strict procedures.

For several reasons, the data provided by the chemical analysis of a small portion of a collection are inadequate for use in the study of ancient economy. First, because chemical sourcing is destructive, it is never random. Unique artifacts, pieces found in special contexts, and other important specimens are excluded routinely from samples chosen for chemical assay (Braswell et al. 1994:178). Such artifacts often are of great interest to archaeologists, because their value as items of prestige or status makes them likely candidates for interregional or long-distance exchange. By analyzing only those artifacts judged to be expendable, we create a systematic bias against whole classes of commodities that were important to the political economy. Second, certain obsidian sources may have been used preferentially for producing specific tool types. We cannot extrapolate source data derived from ubiquitous prismatic blade fragments to less-common projectile points or eccentrics. Thus, if we are to understand lithic production and exchange systems, we cannot routinely exclude certain classes of artifacts from source analyses. This sampling bias has led to the suggestion that the Maya may not have made bifaces of El Chayal obsidian (Moholy-Nagy 1999:304), when the simple truth is that we have not assayed many "gray" bifaces. Third, important goals of economic analysis should be the estimation of the quantities of particular goods that were imported or produced locally during different periods, and the measurement of changes in procurement, production, and consumption patterns. Source data derived from small samples preclude such analyses.

In sum, the importance of obsidian provenance data is not that we can build hypotheses about trade routes from a handful or a breadbox-full of artifacts (e.g., Hammond 1972; Nelson 1985), but that we can study—from a diachronic perspective—broader issues of prehistoric economy. If we are limited to provenance data derived from a small number of artifacts, it is difficult to reconstruct patterns of production, exchange, and consumption. Detailed economic analysis is not possible when source provenance data are derived from a small sample, because only rarely is there a clear way to extrapolate these data to the entire obsidian assemblage. We should aim to source large samples drawn from all artifact types or, if possible, to source all obsidian artifacts in a collection.

Visual Sourcing

What is desired, then, is an accurate, rapid, and nondestructive source attribution technique that can be used in the field laboratory. One approach that clearly meets most of these criteria is visual sourcing. In this method, obsidian artifacts are sorted into categories defined by optical criteria, including: (1) the refracted color; (2) the reflected color; (3) the degree of translucence and opacity; (4) the degree to which refracted light is diffused; (5) the presence, size, color, frequency, and nature of inclusions; (6) the texture and luster of flaked surfaces; and (7) the color, texture, and thickness of cortex (Aoyama 1994, 1996, 1999; Aoyama et al. 1999; Braswell et al. 1994; Clark 1988; Clark and Salcedo 1989; Heller and Stark 1998; McKillop 1989, 1995). The optical criteria we use for identifying artifacts from the three principal obsidian sources in the Maya region are presented in Table 1.

Ample and complete reference collections are critical to visual sourcing. We advocate the use of both previously assayed artifacts and geological samples when making source attributions. It is important that the artifact reference collection contain pieces of varying size and thickness, as well as examples of all the artifact types likely to be found at archaeological sites. If a particular source is visually heterogeneous, artifacts presenting the full range of optical variation should be present in the reference collection. Geological reference samples should be drawn from various outcrops in a source area in order to represent as wide a range of variation as possible. When close correspondences are not found with artifacts in the reference collection, the analyst may make visual source identifications by using flakes knapped from geological samples.

Adequate lighting also is important to visual sourcing. Braswell favors the use of a variety of light sources, ranging from natural sunlight to fluorescent. In contrast, Clark prefers to use the same light source for consistency. Bright light is most helpful when studying dark or completely opaque artifacts, but sunlight and very bright incandescent bulbs may "wash out" differences in the refracted colors of more translucent pieces. Flourescent tubes highlight some differences of hue that are obscured by warm incandescent sources. A white background, either a cloth or a piece of paper, often aids in comparison of both refracted and reflected color.

The first four authors of this report each have found visual sourcing to yield generally consistent and reliable results for obsidian collections from throughout the Maya region.[1] We each have checked our results through chemical assay, and for most archaeological assemblages we have demonstrable accuracy rates upwards of 95 percent (e.g., Aoyama 1991; Braswell et al. 1994; Braswell et al. 1999; McKillop 1995). Together with Glascock, we advocate the judicious use of a combined strategy of the visual sourcing of *complete* collections, accompanied with the *limited* testing of these results through compositional assay.

Despite our success and that of several Guatemalan scholars who also use the method (e.g., Carpio Rezzio 1993; Sánchez Polo 1991), visual sourcing remains a controversial technique. Some Maya lithic analysts have expressed their doubts in print, and many more remain unconvinced of the efficacy of the method. Common criticisms are that certain sources are highly variable, and hence difficult to identify (Moholy-Nagy and Nelson 1990), that samples chosen for both visual sourcing and chemical assay are not random (see Braswell et al. 1994), and, most importantly, that independent scholars have not demonstrated the *reproducibility* of their results. This report demonstrates that, at least for certain collections of Maya obsidian, visual sourcing is both reproducible and accurate.

A Test of Visual Sourcing

In 1991 and 1993, Braswell conducted typological and attribute analyses of 1,501 obsidian artifacts from Chitak Tzak, a highland Maya site located near Sumpango, department of Sacatepéquez, Guatemala (Figure 1). Surface survey and excavations of the site were directed by Eugenia J. Robinson (1994, 1997) as part of the continuing Proyecto Arqueológico del Área Kaqchikel. Although the visible architecture at the site dates to the Late Postclassic period, when Chitak Tzak was a secondary settlement in the Iximche' polity, substantial quantities of both Late Postclassic and Early Classic ceramics and obsidian were collected from the site.

Each obsidian artifact from Chitak Tzak was attributed to a geological source according to visual criteria. Braswell determined that obsidian from San Martín Jilotepeque (n = 786, 52.4 percent) is the most common material represented in the collection, a result that is not surprising because the site is located only 20 km south of that source area. Obsidian from El Chayal (n = 677, 45.1 percent) also is common, and a small number of artifacts from the Ixtepeque (n = 29, 1.9 percent) and San Bartolomé Milpas Altas (n = 9, 0.6 percent) sources were identified.[2] A random sample of 36 artifacts was drawn from Suboperation 21 and four of its extensions for chemical assay according to abbreviated NAA (Glascock et al. 1994; Glascock et al. 1998). The sample consisted of seven percussion flakes, two chunks (a debitage taxon), and 27 whole and fragmentary prismatic blades.

Table 1. Visual attributes of the three common Guatemalan obsidians.

Source	Refracted Color	Reflected Color	Translucency/ Opacity	Sharp/ Diffused	Inclusions	Luster and Texture of Surface	Cortex
El Chayal	Frequently medium gray with milky or waxy appearance, thickest portion often has roseate hue. Less commonly, clear, dark gray, or black.	Medium gray to black.	Medium translucency but banded portions are opaque.	Diffused light, appearance similar to frosted glass.	Frequent but small, dark gray or black banding and dusty inclusions are common in clearer examples. When present, banding is wide and and somewhat irregular.	Medium luster, soap-stone texture, fine unmarred surface.	Generally thin and relatively smooth.
Ixtepeque	Usually brown, similar in color to dark sherry or cola. Rare pieces are completely opaque.	Black but opaque pieces are medium gray. Mahogany spots are frequent on opaque nodules, but rare on artifacts.	Most commonly medium trans-lucency, but banded portions are opaque. Completely opaque pieces are found.	Sharp refracted light, like artificial glass.	Usually none, though banding (typically milky gray to black) is common. Bands are narrow, straight, and parallel. Infrequently, cola-colored material has sand-grain-sized inclusions, but dusty inclusions are absent.	High luster unless opaque gray, which has medium luster. Surface typically is very smooth and glassy, though pieces with sandy inclusions may be somewhat pitted.	Generally quite thin and regular, often with perlitic surface.
San Martin Jilotepeque	Usually dark gray with some brown hue. Highly variable and dependent on density of part-iculate inclusions.	Black.	Low to medium, irregular depending on density of inclusions.	Highly variable, though generally falling between El Chayal and Ixtepeque in the degree of diffusion.	Ubiquitous and of all sizes from dusty to sand-grain-sized particles. Inclusions are distributed throughout in clouds, very uneven black bands, and other irregular formations. Inclusions are much more dense than in other two sources. Some pieces have irregular mahogany or black spots.	Low luster, though the surface can have an oily sheen. Sur-face is pitted due to inclusions, and has an "orange skin" appearance. Least glassy of the three major sources.	Medium to thick, often rough.

Figure 1. Location of Chitak Tzak, department of Sacatepéquez, Guatemala, and the four obsidian sources represented in the archaeological assemblage of the site (a = San Martín Jilotepeque; b = El Chayal; c = Ixtepeque; d = San Bartolomé Milpas Altas).

Before sending the collection to Glascock at the Missouri University Research Reactor, Braswell contacted Clark, Aoyama, and McKillop, and asked them each to source the sample according to their own visual procedures. None of the four participants had worked together in the laboratory, discussed their procedures, or compared results. It should be stated that in 1993, although Clark and McKillop knew each other, neither Aoyama nor Braswell had met Clark, Aoyama and McKillop did not know each other, and Braswell knew Aoyama and McKillop only slightly. Each participant was told what Braswell already knew: the location of the site and that it was occupied in both the Early Classic and Late Postclassic periods. Clark, Aoyama, and McKillop were not informed of Braswell's results until they had finished their own studies, nor did they discuss the test with each other. Thus, the four rounds of visual sourcing were conducted as a blind test. After all four analysts had made source attributions, the sample was sent to Glascock who, in turn, was unaware of the results of visual sourcing.

Table 2 summarizes six-element abbreviated NAA results for the 36 pieces from Chitak Tzak. Figure 2 is a plot of their manganese and sodium concentrations: two elements that are particularly diagnostic for distinguishing among the Guatemalan obsidian sources. Table 3 compares the results of the four independent visual sourcing experiments with Glascock's NAA results. Our names have been

Table 2. Element concentrations for obsidian artifacts for Chitak Tzak, Guatemala.

Sample ID	Ba (ppm)	Cl (ppm)	Dy (ppm)	K (%)	Mn (ppm)	Na (%)
GEB001	1146	480	1.82	3.46	547	2.94
GEB002	833	487	2.73	3.45	641	3.03
GEB003	1079	566	2.29	3.29	520	2.82
GEB004	1094	484	2.08	3.16	520	2.81
GEB005	1041	597	2.23	3.60	461	2.98
GEB006	1169	483	2.27	3.75	526	2.87
GEB007	1162	721	2.74	3.57	482	3.07
GEB008	937	530	2.39	3.29	646	3.02
GEB009	1016	583	2.33	3.14	545	2.90
GEB010	1058	447	2.15	3.35	534	2.90
GEB011	1053	595	2.26	3.25	533	2.87
GEB012	998	513	2.16	3.30	633	2.99
GEB013	1136	517	1.91	3.52	534	2.86
GEB014	926	569	2.52	3.33	631	2.98
GEB015	1106	534	2.19	3.39	537	2.91
GEB016	918	492	2.78	3.77	637	3.02
GEB017	832	464	2.57	3.40	660	3.10
GEB018	947	530	1.88	3.45	648	2.95
GEB019	1015	488	2.57	3.56	669	3.14
GEB020	1025	577	1.81	3.70	537	2.90
GEB021	1061	507	1.91	3.45	529	2.86
GEB022	1157	428	1.89	3.35	550	2.96
GEB023	934	658	2.53	3.21	636	2.99
GEB024	858	594	2.51	3.20	647	3.06
GEB025	1129	501	2.02	3.48	533	2.88
GEB026	1212	600	1.79	3.60	531	2.86
GEB027	1057	483	1.48	3.37	536	2.90
GEB028	876	473	2.76	3.50	654	3.09
GEB029	812	579	2.19	3.29	634	3.04
GEB030	1089	591	2.00	3.57	517	2.79
GEB031	822	572	2.67	3.26	634	2.98
GEB032	1069	582	1.75	3.49	532	2.86
GEB033	838	480	2.33	3.31	655	3.08
GEB034	1096	661	2.22	3.61	545	2.94
GEB035	875	473	2.88	3.33	646	3.07
GEB036	1137	580	1.58	3.77	531	2.82

removed from Table 3 in order to focus attention on the overall homogeneity of our results.

Statistical Analysis

Two aspects of the data in Table 3 are particularly worthy of note. First, the results of the four independent attempts at visual sourcing are remarkably consistent. On an artifact-by-artifact basis, source identifications made by three individuals (A, B, and C) all agree. Identifications made by investigator D match those of the other three researchers for 34 cases, but disagree for two artifacts (samples GEB005 and GEB023). To put it another way, 97.2 percent of all pairs of observations (i.e., two

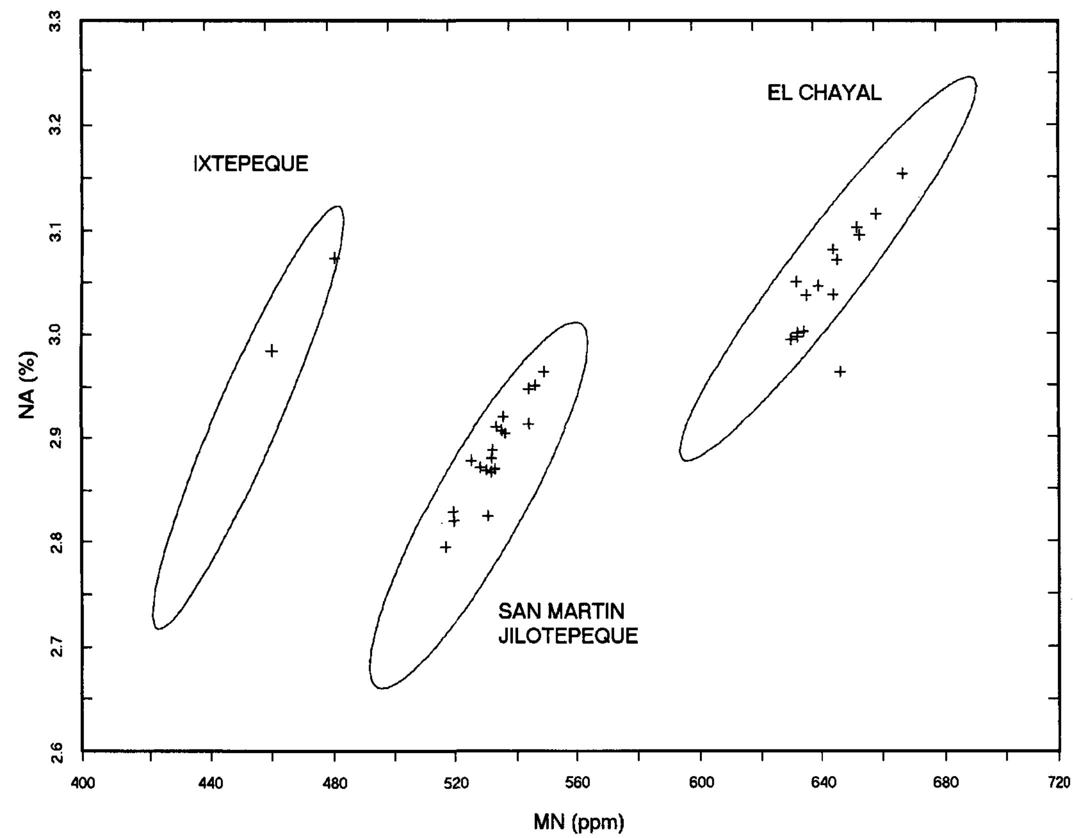

Figure 2. Manganese (parts per million) and sodium (percent) concentrations of 36 obsidian artifacts from Chitak Tzak (ellipses indicate 95-percent confidence limit for assignment to each source).

observers assigning a source to the same artifact) agree. Furthermore, the slight discrepancy in the four attempts at visual sourcing is important only if the source of each particular piece needs to be known. That is, the summary results for each attempt at visual sourcing are identical: all four researchers concluded that 19 artifacts come from the San Martín Jilotepeque source, 16 from El Chayal, and one from Ixtepeque.

The data in Table 3 also demonstrate that visual sourcing is highly accurate. Six-element abbreviated NAA confirms that investigators A, B, and C identified the correct geological source for 35 of the 36 artifacts. Researcher D's visual assignments were correct for 33 artifacts. Oddly, all four attempts at visual sourcing agreed that one artifact (sample GEB007) came from the El Chayal source. Abbreviated NAA suggested that the piece came from Ixtepeque. Given the unanimity of the visual source assignments and their disagreement with the abbreviated NAA result, we decided to reanalyze the artifact using 28-element NAA. This full-complement analysis supported the result of abbreviated NAA and demonstrated that not one of us was able to identify correctly the source of this artifact. Still, the individual success rates for visual sourcing of the random sample from Chitak Tzak ranged from 92 to 97 percent, and averaged 96 percent.

What is the probability of such a remarkable consensus in the results of visual sourcing generated by four independent researchers? In addition, how confident can we be that the great concordance between the visual sourcing and NAA results is not merely a coincidence? To phrase it differently, at a given confidence level, what is the reproducibility and accuracy of visual sourcing for this collection?

One conservative approach to the problem of reproducibility is to pretend that the summary results were *known* to the researchers. That is, to ask: if the summary visual results (19 artifacts from San Martín

Table 3. Results of visual sourcing and abbreviated neutron activation analysis for obsidian artifacts from Chitak Tzak, Guatemala (CHY = El Chayal, IXT = Ixtepeque, SMJ = San Martín Jilotepeque; incorrect visual identifications are shown in bold italics).

Sample ID	Visual Sourcing Results A	B	C	D	NAA
GEB001	SMJ	SMJ	SMJ	SMJ	SMJ
GEB002	CHY	CHY	CHY	CHY	CHY
GEB003	SMJ	SMJ	SMJ	SMJ	SMJ
GEB004	SMJ	SMJ	SMJ	SMJ	SMJ
GEB005	IXT	IXT	IXT	***CHY***	IXT
GEB006	SMJ	SMJ	SMJ	SMJ	SMJ
GEB007	***CHY***	***CHY***	***CHY***	***CHY***	IXT
GEB008	CHY	CHY	CHY	CHY	CHY
GEB009	SMJ	SMJ	SMJ	SMJ	SMJ
GEB010	SMJ	SMJ	SMJ	SMJ	SMJ
GEB011	SMJ	SMJ	SMJ	SMJ	SMJ
GEB012	CHY	CHY	CHY	CHY	CHY
GEB013	SMJ	SMJ	SMJ	SMJ	SMJ
GEB014	CHY	CHY	CHY	CHY	CHY
GEB015	SMJ	SMJ	SMJ	SMJ	SMJ
GEB016	CHY	CHY	CHY	CHY	CHY
GEB017	CHY	CHY	CHY	CHY	CHY
GEB018	CHY	CHY	CHY	CHY	CHY
GEB019	CHY	CHY	CHY	CHY	CHY
GEB020	SMJ	SMJ	SMJ	SMJ	SMJ
GEB021	SMJ	SMJ	SMJ	SMJ	SMJ
GEB022	SMJ	SMJ	SMJ	SMJ	SMJ
GEB023	CHY	CHY	CHY	***IXT***	CHY
GEB024	CHY	CHY	CHY	CHY	CHY
GEB025	SMJ	SMJ	SMJ	SMJ	SMJ
GEB026	SMJ	SMJ	SMJ	SMJ	SMJ
GEB027	SMJ	SMJ	SMJ	SMJ	SMJ
GEB028	CHY	CHY	CHY	CHY	CHY
GEB029	CHY	CHY	CHY	CHY	CHY
GEB030	SMJ	SMJ	SMJ	SMJ	SMJ
GEB031	CHY	CHY	CHY	CHY	CHY
GEB032	SMJ	SMJ	SMJ	SMJ	SMJ
GEB033	CHY	CHY	CHY	CHY	CHY
GEB034	SMJ	SMJ	SMJ	SMJ	SMJ
GEB035	CHY	CHY	CHY	CHY	CHY
GEB036	SMJ	SMJ	SMJ	SMJ	SMJ

Jilotepeque, 16 from El Chayal, and one from Ixtepeque) were known ahead of time, what would be the chances that the researchers would assign the same result to each piece? To simplify the problem further in order to aid in calculations, let us assume that one set of results (say A's) forms a reference sample. That is, given A's results on a piece-by-piece basis, and given that the other researchers knew how many times A assigned a particular source (and which sources they were), what is the probability that investigators B and C would make precisely the same assignments as A, and that researcher D would differ in only two? In essence, this reduces the problem to modeling a probability as sampling without replacement.

If we consider D's experiment and assume sampling without replacement, there are 339 ([36!/34!2!] - [19!/17!2!] - [16!/14!2!]) possible ways to differ in only two attributions. Not all of these have the same probability of occurrence. Calculating the total probability of achieving this degree of agreement with the other three analysts is possible, but tedious. A final conservative simplification, therefore, is to consider only the concordance of B and C's results with A's, that is, to ignore investigator D's assignments even though they greatly support the reproducibility of visual sourcing.

Given the above very conservative stipulations, the probability of B agreeing with A on each identification is 1 in 146,157,442,200, or 6.84×10^{-12}. If we also consider C, the probability drops to 1 in 21,361,997,910,446,300,000,000, or 4.68×10^{-23}. These are extremely long odds: approximately 100 times worse than hitting the PowerBall Lotto (all five balls *plus* the bonus) twice in a row. If we factor in D's results, the total probability decreases to something on the order of 10^{-35}. Clearly, with these observers and this data set, visual sourcing is not random and is highly reproducible. Again, this is a conservative estimate because the problem is modeled as sampling without replacement. In reality, the researchers did not know which sources would be in the sample and what their relative frequencies would be.

Another way to consider reproducibility is to calculate Cohen's *k* (Cohen 1960), used as a measure of agreement between the ratings of pairs of observers. The simplest measure of agreement, of course, is just the number of identical observations divided by the total: in this case 100 percent for any pair drawn from analysts A, B, and C, or 94 percent (34/36) for any pair of observers containing investigator D. But this does not correct for chance agreement. For example, all four observers attributed 53 percent (19/36) of the collection to San Martín Jilotepeque. Given any independent pair of observers, we would expect that approximately 28 percent of the pieces would be identified by both as obsidian from that source. A simple correction, then, is 53 percent - 28 percent = 25 percent. Cohen's *k* is a normalization of this probability, calculated by dividing it by the largest possible difference in the marginal totals of the cross tabulation. Tests of the null hypothesis that $k = 0$ can be calculated from the ratio of k to its standard error.

Any pair of the four raters that does not include researcher D yields $k = 1$. The asymptotic standard error is 0, T is approximately 6.481, and the resulting p is approximately 0. If D is paired with A, B, or C, $k = .894$, the asymptotic standard error is .069, T is approximately 5.792, and the resulting $p << .0005$. Thus, the null hypothesis that the degree of agreement between any two observers is a chance result can be rejected with near certainty.

The simplest measure of accuracy of the visual sourcing of this sample is the total number of correct identifications out of all attempts, or 96 percent (138/144). But what, at the 95-percent confidence level, is the probability of any piece in the collection being identified correctly by visual sourcing? If we assume that the four researchers in this study are the only lithic analysts who practice visual sourcing, the standard deviation in our individual accuracy rates is 2 percent. Thus, at the 95-percent confidence level, our true accuracy rates for this collection are greater than 91 percent. If, on the other hand, the four of us are considered to be drawn from a larger population of archaeologists who practice the method, the 95-percent confidence level for the accuracy of visual sourcing of this collection is 90–100 percent. Hence, with a high degree of certainty, visual source identifications for the Chitak Tzak assemblage are *at least* 90 percent accurate.

Interpretation and Previous Tests of Visual Sourcing

Statistical analyses indicate that for the Chitak Tzak sample, visual sourcing is highly reproducible among different analysts with experience in the method. Moreover, the successful attribution rate (as measured against NAA results) is quite high. Although other investigators might decide that an overall accuracy rate of approximately 96 percent (with a 2-σ range of 91–100 percent) is insufficient for their work, we find this success rate more than adequate for our own research. Moreover, the large samples that can be studied using visual sourcing allow us to form more statistically sound interpretations of ancient Maya exchange.

The tested sample from Chitak Tzak contained artifacts from only three sources and cannot be taken as representative of all collections from all sites in the Maya region. What additional information can be gleaned from this data set that may be applicable to other samples from other sites?

In all cases, visual sourcing successfully distinguished San Martín Jilotepeque obsidian from material from the other two sources. We expect, then, that this would tend to be true for samples from other sites. Only two artifacts from the Ixtepeque source were present in the collection. One was misidentified as El Chayal by all four visual analysts. Moreover, one researcher misidentified an Ixtepeque artifact as coming from El Chayal, and mis-assigned an El Chayal piece to Ixtepeque. This suggests that differentiating between Ixtepeque and El Chayal obsidian is more difficult than distinguishing San Martín Jilotepeque from either El Chayal or Ixtepeque.

Unfortunately, the sample size for Ixtepeque ($n = 2$) is too small to determine whether the confusion of Ixtepeque and El Chayal is significant. Still, 98 percent (59/60) of the visual source identifications for artifacts from the El Chayal source were correct. This is actually higher than our overall success rate for the entire sample. Thus, although some Ixtepeque obsidian may overlap with our visual criteria for El Chayal, it is less likely that we would misidentify El Chayal obsidian as coming from Ixtepeque.

The apparent lack of symmetry in distinguishing between Ixtepeque and El Chayal obsidian may be related to experience with material from those sources. Aoyama and Braswell each have worked extensively in western Honduras, and between them have analyzed more than 110,000 Ixtepeque artifacts from Copán, La Entrada, and other regions in the southeast periphery. Studying these collections and geological samples from Volcán de Ixtepeque, they have seen the full range of visual variation present in material from that source. In contrast, Ixtepeque obsidian is less common in the Belizean cayes and in Chiapas, where McKillop and Clark have conducted much of their research. In addition, collections from the Belizean cayes often contain obsidian from multiple sources (six have been identified at Wild Cane Caye [McKillop et al. 1988]), so an analyst with experience in that region might expect more diversity in collections from other areas. Moreover, Clark has studied many more artifacts from Tajumulco and the highland Mexican sources than the other three analysts, Aoyama is the only one with significant experience recognizing two Honduran sources (San Luis and Esperanza), and Braswell has conducted extensive research in San Martín Jilotepeque. It is reasonable to expect that each of us would be more accurate in identifying material from the sources that we know well. Thus, visual sourcing results may reflect disparate areas of study and degrees of familiarity with material from different sources, as well as prior expectations regarding source diversity.

How difficult is it to distinguish between El Chayal and Ixtepeque obsidian? Since only two artifacts in the Chitak Tzak collection come from the Ixtepeque source, it is necessary to look at other tests of visual sourcing to obtain an estimated accuracy rate. Aoyama (1991), Braswell et al. (1994), and McKillop (1995) all have published results of previous tests of the efficacy of visual sourcing. McKillop (1995:Table 28) made source assignments for 44 artifacts from San Juan Ambergris Caye, 36 of which had been attributed to geological sources by XRF (see Guderjan et al. 1989).[3] Thirty-five of these came from either El Chayal (n = 31) or Ixtepeque (n = 4). Only one error was made; an Ixtepeque piece was mistakenly attributed to the El Chayal source. This was not a completely blind test. The summary results for 36 of the 44 artifacts were known to McKillop before she began her visual analysis of the collection.

In a blind experiment, Aoyama (1991) and Glascock analyzed a random sample of 100 obsidian artifacts from the La Entrada region. The sample included 61 pieces from the Ixtepeque source and four from El Chayal. Aoyama correctly identified all 61 Ixtepeque artifacts, but two particularly small El Chayal artifacts were given incorrect attributions; one was assigned to Ixtepeque and one to San Martín Jilotepeque (Aoyama 1991:Cuadro VI-57). In one sense, this error is the opposite of those committed by researchers A, B, and C in the current study. In the Chitak Tzak sample, these three analysts successfully identified all the El Chayal obsidian but misidentified a single piece of Ixtepeque. In another sense, the error is similar; one artifact from a minor source in each collection was mistakenly attributed to a more common source. This implies that when conducting visual sourcing, analysts should not automatically assign an artifact with ambiguous visual characteristics to the dominant source.

Braswell encountered the opposite problem in his study of 48 Ixtepeque and El Chayal artifacts from Quelepa, El Salvador (Braswell et al. 1994). In that case, all nine artifacts from the minor source of El Chayal were correctly attributed, but three pieces from the predominant source of Ixtepeque were misidentified as coming from El Chayal. The lesson to be drawn from this third example is that an analyst should not be over-eager to identify uncommon sources in essentially homogeneous collections. To be fair, both the La Entrada and Quelepa tests were conducted at times when Aoyama and Braswell were relatively inexperienced at visual analysis. A further note of caution is that identifications become easier and more accurate with increased experience. Finally, Aoyama's (1991) experiment demonstrates that it is often difficult to identify correctly the geological source of very small artifacts.

A total of 165 artifacts chemically provenanced to the Ixtepeque (n = 106) and El Chayal (n = 59) sources were given visual source assignments in the current study and in these three previous tests. In all, 216 visual attributions were made for these artifacts (the 17 pieces from El Chayal and Ixtepeque that are in the Chitak Tzak sample each were analyzed four times). Only 12 incorrect assignments were made out of 216 attempts, that is, the success rate for distinguishing between El Chayal and Ixtepeque was 94.4 percent. Thus, although obsidian from Ixtepeque and El Chayal are not as visually distinctive as material from San Martín Jilotepeque, they can be distinguished from each other with a high degree of success.

A Combined Approach to Obsidian Sourcing and a Suggested Sampling Strategy

The visual identification of obsidian from the three important Guatemalan sources is highly accurate, but not quite as reliable as NAA or XRF. Nonetheless, there are benefits to sourcing entire collections that far outweigh the slight increase in error associated with visual sourcing. Archaeologists with limited funds or those who cannot transport their collections to a laboratory for compositional analysis should invest the time and effort needed to learn visual sourcing.

For those who can conduct XRF or NAA on small samples drawn from their collections, we advocate a combined strategy that entails both visual and compositional analyses. We have found that the best approach to obsidian sourcing—one that minimizes cost and artifact destruction yet maximizes accuracy and the sample size of sourced artifacts—is the use of visual sourcing for an entire collection coupled with limited, nonrandom sampling for NAA or XRF.

At many sites in the Maya region, almost all obsidian comes from one or two of the Guatemalan sources (see note 1). One approach to source identification is to draw a small (10 to 30 artifacts) random sample from each of the visual categories thought to represent these sources. In addition, all pieces that appear unusual and may come from other sources should be subject to compositional analysis. Braswell has used this nonrandom sampling strategy to study collections from Calakmul (Braswell et al. 1999), Topoxté (Braswell 1999), Ek Balam and Yaxuná (Braswell 1998), and a sample from the non-Maya site of Quelepa (Braswell et al. 1994). McKillop et al. (1988) selected a sample of five visually unusual obsidian artifacts from Wild Cane Caye for chemical analysis, and all were identified as coming from sources that are uncommon in the assemblage. This strategy maximizes the chance of identifying all the rare sources, often Mexican, that easily are missed when drawing a small, random sample from a large collection (Braswell et al. 1994; McKillop 1987, 1989; McKillop and Jackson 1988). Such sources may not constitute a significant portion of the total assemblage, but they are important for understanding long-distance exchange systems.[4] The sample drawn from the predominant source categories allows a quick check of the accuracy of their visual identification.

In cases where many sources are present in substantial quantities, such as at Chichén Itzá (Braswell 1997b, 1998), it may be necessary to draw a random sample for compositional analysis from each visual category. In this strategy, visual sourcing is considered successful if each visual category is shown to consist of one and only one source. Occasionally, a visual category may contain more than one source. If the sample has been drawn randomly, it should reflect the population as a whole, so compositional results can be extrapolated to the entire suspect visual category. Thus, although the source of each piece in the source-heterogeneous visual category will not be known, the proportion of those sources within the entire collection can be estimated. If piece-specific or context-specific results are needed, a second round of chemical analysis may be conducted on the entire source-heterogeneous category.

The Development of Visual Sourcing Throughout Latin America

Obsidian specialists working in other regions of the Americas may ask if visual sourcing has general applicability, that is, can it be employed elsewhere with equivalent success? Braswell (1997a; Braswell et al. 1995) has used visual sourcing to study la collections from lower Central America, particul from Pacific Nicaragua. In that region, most ob ian comes from the Güinope, Honduras, source, minor sources (including Ixtepeque, El Chayal, San Martín Jilotepeque) also are found in some s ples, especially those dating to the Sapoá-Omet periods. He has found that Güinope obsidian is tinctive and easily identifiable, and accuracy rates visual sourcing are equivalent to those achieved v Maya collections.

Obsidian sources are less abundant in Cen America than in highland Mexico, which com cates the use of visual sourcing in that region. Doz of poorly known sources are represented in coll tions from sites in the northwest periphery Mesoamerica (Trombold et al. 1993). Moreo materials from certain central Mexican sour appear somewhat similar. In particular, the Mexi "black" obsidians present some difficulties, es cially when distinguishing between material fr Ucareo, Michoacán, and Zaragoza, Puebla (Brasv 1997b). But widespread distribution of Ucareo ob ian was limited largely to the Epiclassic period, material from that source is not common at m Mexican sites where Zaragoza obsidian is found quantity (Braswell 2000). Fortunately, other comn highland sources, particularly Paredón and Pico Orizaba, are as easy to identify as green obsid from Pachuca, Hidalgo. Moreover, the technic already has been shown to have great potential in c tain regions (e.g., Heller and Stark 1998). Con quently, although we caution that it may be diffic to make visual source attributions for some coll tions from northwest Mesoamerica, we anticip that the technique will be highly successful in mu of highland Mexico.

Current understanding of Andean obsidi sources is limited, but important advances have be made (e.g., Asaro et al. 1994; Burger et al. 19 1998a, 1998b, 1998c; Seelenfreund et al. 199 Recent research in Peru provides an example of h visual source analysis could be developed in are outside of Mesoamerica.

The first step in developing visual sourcing i new regions is the identification of sources that m appear in archaeological collections. This is acco plished through geological prospecting and comp sitional assay. Unfortunately, noneconom geological investigations have received little pri

https://doi.org/10.2307/972178 Published online by Cambridge University Press

ity in Peru until quite recently (Burger et al. 1998b:186). Nevertheless, three principal sources exploited by ancient inhabitants of the central Andes (Quispisisa, Department of Ayacucho), the Cuzco Basin (Alca, Department of Arequipa), and the Titicaca Basin (Chivay, Department of Arequipa) have been identified (Burger et al. 1998a, 1998b; Burger and Glascock 2000). These sources in southern Peru account for 81 percent of 812 artifacts collected from 141 archaeological sites in the region (Burger et al. 1998b:185). Still, the locations of sources corresponding to several additional chemical groups are not yet known.

The second step is the chemical assay of artifacts, with the goal of creating useful reference collections. In Peru, at least 1,314 artifacts have been assayed (Burger 1980, 1981; Burger and Asaro 1978, 1993; Burger et al. 1984, 1994, 1998b). The third step, the establishment of comparative visual collections and the definition of optical criteria to be used to distinguish obsidian from distinct sources, has not yet been attempted in the Andean region. Our experience suggests that a sufficient number of artifacts from Peru and northern Bolivia have been assayed for this to be accomplished. Moreover, since only 10 chemical groups are represented in these collections, it should not be too onerous a task. Given the fact that the vast majority of assayed artifacts come from only three sources, it may be sufficient to proceed with criteria for these alone. When studying collections from southern Peru and Bolivia, we suggest the first sampling strategy described above. A small number of pieces could be drawn for chemical analysis from visual categories thought to represent the common sources, and all pieces that do not appear to come from these sources could be assayed by NAA or XRF.

Conclusions

Despite published doubts about the efficacy of visual sourcing (e.g., Moholy-Nagy and Nelson 1990), experienced visual analysts can distinguish consistently among the three major obsidian sources represented in collections from the Maya region. Obsidian from San Martín Jilotepeque is the most distinctive, but we also have identified Ixtepeque and El Chayal obsidian correctly in 94.4 percent (204/216) of our attempts. Visual identifications of these three Maya sources, and also of the most-common Mexican source (Pachuca, Hidalgo) represented at Maya sites, are highly accurate, and we have demonstrated that accuracy in four tests using NAA and XRF results.

Visual sourcing results for obsidian from the Maya region also are highly *reproducible* among independent observers. In 1993, when we conducted our test of the Chitak Tzak material, the four participants knew each other only poorly, if at all. Yet our results are almost identical, with a pair-wise agreement rate of 97.2 percent over all observations. A highly conservative probabilistic model (one that assumes that the summary results were known to the four visual analysts) demonstrates that the chance of such a degree of concordance being a random event is astronomically small. Moreover, calculations of Cohen's *k*, used to measure the level of agreement between pairs of raters, also indicate that our degree of consensus should not be considered a random event, with probability levels so low that they are nearly incalculable.

Lithic specialists who work in the Maya area should learn to differentiate among the three principal Guatemalan sources, because visual sourcing allows the geological provenance of large collections—rather than small, usually nonrandom samples—to be determined. Although compositional assay of small samples permits the formation of general hypotheses concerning trade routes (e.g., Hammond 1972, 1976; Nelson 1985), it precludes more detailed analyses of ancient economy. We suggest that other Latin Americanists interested in production, exchange, and consumption patterns would do well to employ our method if relatively few sources are represented in their archaeological collections, and if those sources are sufficiently distinct in appearance to allow visual sourcing. Since only three sources make up the vast majority of collections from Peru and northern Bolivia, and because even fewer sources were used in ancient Ecuador (Asaro et al. 1994; Burger et al. 1994), we suggest that Andean South America may be a suitable place to employ the procedure. Moreover, the efficacy of visual sourcing already has been demonstrated in lower Central America (Braswell 1997a; Braswell et al. 1995), and in certain regions of Mexico (e.g., Heller and Stark 1998). Nonetheless, we caution that it may be somewhat more difficult to develop the technique in central Mexico, where two important sources are similar in appearance, and in the northwestern frontier of Mesoamerica, where many sources were used in ancient times.

We caution that the success of visual sourcing is related to experience; scholars should not expect to achieve very low error-rates after only one day experimenting with the technique. Moreover, lithic analysts, particularly those new to the method, should use a comparative reference collection. This should contain both artifacts and geological specimens that exhibit the full range of visual attributes associated with each source likely to be found in an archaeological assemblage. We suggest that the best strategies for determining geological provenance involve a combined approach of complete visual sourcing coupled with limited compositional analysis. The latter should be used to source pieces of uncertain geological provenance, as well as to demonstrate the source-homogeneity of visual categories established by the analyst. Although these are not purely random sampling strategies, we have found that they allow the largest quantity of artifacts to be accurately sourced at a low cost, and for the error rates associated with visual sourcing to be calculated.

Acknowledgments. Neutron activation analysis of the Chitak Tzak sample was supported by grants from the National Science Foundation (DBS-9102016, awarded to Michael D. Glascock) and the Wenner-Gren Foundation (awarded to Eugenia J. Robinson). The authors thank Brydon J. B. Grant and Jacek Dmochowski of SUNY-Buffalo for their advice and help with statistical analysis. Our colleagues Jennifer B. Braswell and Rafael Cobos were kind enough to edit the Spanish abstract.

References Cited

Andrews, A.P., F. Asaro, H. V. Michel, F. H. Stross, and P. Cervera Rivero
1989 The Obsidian Trade at Isla Cerritos, Yucatán, Mexico. *Journal of Field Archaeology* 16:355–363.

Aoyama, K.
1991 Lítica. In *Investigaciones arqueológicas en la región de La Entrada,* vol. 2, edited by S. Nakamura, K. Aoyama, and E. Uratsuji, pp. 39–203. Servicio de Voluntarios Japoneses para la Cooperación con el Extranjero y el Instituto Hondureño de Antropología e Historia, San Pedro Sula.
1994 Socioeconomic Implications of Chipped Stone from the La Entrada Region, Western Honduras. *Journal of Field Archaeology* 21:133–145.
1996 *Exchange, Craft Specialization, and Ancient Maya State Formation: A Study of Chipped Stone Artifacts from the Southeast Maya Lowlands.* Ph.D. dissertation, Department of Anthropology, University of Pittsburgh. University Microfilms, Ann Arbor.
1999 *Ancient Maya State, Urbanism, Exchange, and Craft Specialization: Chipped Stone Evidence of the Copan Valley and the La Entrada Region, Honduras.* Memoirs in Latin American Archaeology, No. 12. University of Pittsburgh, Pittsburgh.

Aoyama, K., T. Tashiro, and M. D. Glascock
1999 A Pre-Columbian Obsidian Source in San Luis, Honduras: Implications for the Relationship between Late Classic Maya Political Boundaries and the Boundaries of Obsidian Exchange Networks. *Ancient Mesoamerica* 10:237–249.

Arnauld, M. C.
1990 El comercio clásico de obsidiana: rutas entre tierras altas y tierras bajas en el área maya. *Latin American Antiquity* 1:347–367.

Asaro, F., H. V. Michel, R. Sidrys, and F. H. Stross
1978 High-Precision Chemical Characterization of Maya Obsidian Sources in Guatemala. *American Antiquity* 43:436–443.

Asaro, F., E. Salazar, H. V. Michel, R. L. Burger, and F. H. Stross
1994 Ecuadorian Obsidian Sources Used for Artifact Production and Methods for Provenience Assignments. *Latin American Antiquity* 5:257–277.

Braswell, G. E.
1996 *A Maya Obsidian Source: The Geoarchaeology, Settlement History, and Ancient Economy of San Martín Jilotepeque, Guatemala.* Ph.D. dissertation, Department of Anthropology, Tulane University. University Microfilms, Ann Arbor.
1997a El intercambio comercial entre los pueblos prehispanicos de Mesoamérica y la Gran Nicoya. *Revista de la Universidad del Valle de Guatemala* 6:17–29.
1997b El intercambio prehispánico en Yucatán, México. In *X simposio de investigaciones arqueológicas en Guatemala, 1996,* vol 2., edited by J.P. Laporte and H. Escobedo, pp. 545–556. Museo Nacional de Arqueología y Etnología, Guatemala.
1998 Trade, Procurement, and Population: Obsidian and the Maya of the Northern Lowlands. Paper presented at the 97th Annual Meetings of the American Anthropological Association, Philadelphia.
1999 Los artefactos de obsidiana de Topoxté, El Petén, Guatemala. *Beiträge zur Allgemeinen und Vergleichenden Archäologie.* Mainz, in press.
2000 Postclassic Mesoamerican Obsidian Exchange Spheres. In *The Postclassic Mesoamerican World,* edited by M. E. Smith and F. Berdan. University of Utah Press, Salt Lake City, in press.

Braswell, G. E., E.W. Andrews V, and M. D. Glascock
1994 The Obsidian Artifacts of Quelepa, El Salvador. *Ancient Mesoamerica* 5:173–192.

Braswell, G. E., J. D. Gunn, M. del R. Domínguez Carrasco, W. J. Folan, L. Fletcher, and M. D. Glascock
1999 Defining the Terminal Classic at Calakmul. In *The Terminal Classic in the Maya Lowlands: Collapse, Transition, and Transformation,* edited by D. S. Rice, P. M. Rice, and A. A. Demarest. Westview Press, Boulder. In press.

Braswell, G. E., S. Salgado González, and M. D. Glascock
1995 La obsidiana guatemalteca en Centroamérica. In *VIII simposio de investigaciones arqueológicas en Guatemala, 1994,* vol. 1, edited by J. P. Laporte and H. Escobedo, pp. 121–131. Museo Nacional de Arqueología y Etnología, Guatemala.

Burger, R. L.
1980 Trace-Element Analysis of Obsidian Artifacts from Pachamachay, Junin. In *Prehistoric Hunters of the High Andes,* by J. Rick, pp. 257–261. Academic Press, New York.
1981 La procedencia de artefactos de obsidiana en los sitios formativos en Ayacucho: Chupas y Wichqana. *Boletín del Museo Nacional de Antropología y Arqueología* 7:9–10. Lima.

Burger, R. L., and F. Asaro
1978 Obsidian Distribution and Provenience in the Central Highlands and Coast of Peru during the Preceramic Period. *Contributions of the University of California Archaeological Research Facility* 36:61–83.

1993 La distribución y procedencia de artefactos de obsidiana durante el Período Inicial y Horizonte Temprano. In *Emergencia de la civilización en los Andes: Ensayos de interpretación,* by R. L. Burger, pp. 180–231. Universidad Nacional Mayor de San Marcos, Lima.

Burger, R. L., F. Asaro, and H. V. Michel

1984 The Source of Obsidian Artifacts at Chavín de Huántar. In *The Prehistoric Occupation of Chavín de Huántar, Peru,* by R. L. Burger, pp. 263–270. University of California Press, Berkeley.

Burger, R. L., F. Asaro, H. V. Michel, F. H. Stross, and E. Salazar

1994 An Initial Consideration of Obsidian Procurement and Exchange in Prehispanic Ecuador. *Latin American Antiquity* 5:228–255.

Burger, R. L., F. Asaro, G. Salas, and F. Stross

1998a The Chivay Obsidian Source and the Geological Origin of Titicaca Basin Type Obsidian Artifacts. *Andean Past* 5:203–223.

Burger, R. L., F. Asaro, P. Trawick, and F. H. Stross

1998bThe Alca Obsidian Source: The Origin of Raw Material for Cuzco Type Obsidian Artifacts. *Andean Past* 5:185–202.

Burger, R. L., K. J. Schreiber, M. D. Glascock, and J. Ccencho

1998c The Jampatilla Obsidian Source: Identifying the Geological Source of Pampas Type Obsidian Artifacts from Southern Peru. *Andean Past* 5: 225–239.

Burger, R. L., and M. D. Glascock

2000 Locating the Quispisisa Obsidian Source in the Department of Ayacucho, Peru. *Latin American Antiquity* 11:258–268 (current issue).

Carpio Rezzio, E. H.

1993 Obsidian at Balberta. In *The Balberta Project: The Terminal Formative - Early Classic Transition on the Pacific Coast of Guatemala,* edited by F. J. Bove, S. Medrano B., B. Lou P., and B. Arroyo L., pp. 83–106. Memoirs in Latin American Archaeology, No. 6. University of Pittsburgh, Pittsburgh.

Clark, J. E.

1988 *The Lithic Artifacts of La Libertad, Chiapas, Mexico.* Papers of the New World Archaeological Foundation, No. 52. Brigham Young University, Provo.

Clark, J. E., T. A. Lee, Jr., and T. Salcedo

1989 The Distribution of Obsidian. In *Ancient Trade and Tribute: Economies of the Soconusco Region of Mesoamerica,* edited by B. Voorhies, pp. 268–284. University of Utah Press, Salt Lake City.

Clark, J. E., and T. Salcedo

1989 Ocós Obsidian Distribution in Chiapas, Mexico. In *New Frontiers in the Archaeology of the Pacific Coast of Southern Mesoamerica,* edited by F. J. Bove and L. Heller, pp. 15–24. Anthropological Research Papers, No. 39. Arizona State University, Tempe.

Cohen, J.

1960 A Coefficient of Agreement for Nominal Scales. *Educational and Psychological Measurement* 20:37–46.

Dreiss, M. L.

1988 *Obsidian at Colha, Belize: A Technological Analysis and Distributional Study Based on Trace Element Data.* Papers of the Colha Project, vol. 4, Texas Archaeological Research Laboratory. University of Texas, San Antonio.

Dreiss, M. L., and D. O. Brown

1989 Obsidian Exchange Patterns in Belize. In *Prehistoric Maya Economies in Belize,* edited by P. A. McAnany and B. L. Isaac, pp. 57–90. Research in Economic Anthropology, Supplement No. 4. JAI Press, Greenwich, Connecticut.

1991 Socioeconomic Implications of the Distribution of Obsidian in the Late and Terminal Classic Periods at the Maya Site of Colha, Belize. Paper presented at the 47th International Congress of Americanists, New Orleans.

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

1998 A Systematic Approach to Obsidian Source Characterization. In *Archaeological Obsidian Studies: Method and Theory,* edited by M.S. Shackley, pp. 15–65. Plenum Press, New York.

Glascock, M. D., H. Neff, K. S. Stryker, and T. N. Johnson

1994 Sourcing Archaeological Obsidian by an Abbreviated NAA Procedure. *Journal of Radioanalytical and Nuclear Chemistry, Articles* 180:29–35.

Guderjan, T. H., J. F. Garber, H. A. Smith, F. H. Stross, H. V. Michel, and F. Asaro

1989 Maya Maritime Trade and Sources of Obsidian at San Juan, Ambergris Cay, Belize. *Journal of Field Archaeology* 16:363–369.

Hammond, N.

1972 Obsidian Trade Routes in the Maya Area. *Science* 178:1092–1093.

1976 Maya Obsidian Trade in Southern Belize. In *Maya Lithic Studies: Papers from the 1976 Belize Field Symposium,* edited by T. R. Hester and N. Hammond, pp. 71–81. Special Report No. 4, Center for Archaeological Research. University of Texas, San Antonio.

Healan, D. M.

1993 Local versus Non-Local Obsidian Exchange at Tula and Its Implications for Post-Formative Mesoamerica. *World Archaeology* 24:449–464.

Heizer, R. F., H. Williams, and J. A. Graham

1965 Notes on Mesoamerican Obsidians and Their Significance in Archaeological Studies. *Contributions of the University of California Archaeological Research Facility* 1:94–103.

Heller, L., and B. L. Stark

1998 Classic and Postclassic Obsidian Tool Production and Consumption: A Regional Perspective from the Mixtequilla, Veracruz. *Mexicon* 20:119–128.

Hughes, R. E.

1984 Obsidian Sourcing Studies in the Great Basin: Problems and Prospects. *Contributions of the University of California Archaeological Research Facility* 45:1–19.

Jack, R .N., and R. F. Heizer

1968 "Finger-Printing" of Some Mesoamerican Obsidian Artifacts. *Contributions of the University of California Archaeological Research Facility* 5:81–100.

Lewenstein, S. M., and M. D. Glascock

1997 Presencia del altiplano en la región de Comalcalco. *Los Investigadores de la Cultura Maya* 5:205–211. Universidad Autónoma de Campeche, Campeche.

McKillop, H. I.

1987 *Wild Cane Cay: An Insular Classic Period to Postclassic Period Maya Trading Station.* Ph.D. dissertation, Department of Anthropology, University of California–Santa Barbara. University Microfilms, Ann Arbor.

1989 Coastal Maya Trade: Obsidian Densities at Wild Cane Cay, Belize. In *Prehistoric Maya Economies of Belize,* edited by P. A. McAnany and B. Isaac, pp. 17–56. Research in Economic Anthropology, Supplement 4. JAI Press, Greenwich, Connecticut.

1995 The Role of Northern Ambergris Caye in Maya Obsidian Trade: Evidence from Visual Sourcing and Blade Technology. In *Maya Maritime Trade, Settlement, and Populations on Ambergris Caye, Belize,* edited by T. H. Guderjan and J. F. Garber, pp. 163–174. Maya Research Program and Labyrinthos, Lancaster, Pennsylvania.

McKillop, H. I., and L. J. Jackson

1988 Ancient Maya Obsidian Sources and Trade Routes. In *Obsidian Dates IV: A Compendium of the Obsidian Hydra-*

tion Determinations Made at the UCLA Obsidian Hydration Laboratory, edited by C.W. Meighan and J. L. Scalise, pp. 130–141. Monograph No. 29, the Institute of Archaeology. University of California, Los Angeles.

McKillop, H. I., L. J. Jackson, H. V. Michel, F. H. Stross, and F. Asaro

1988 Chemical Source Analysis of Maya Obsidian: New Perspectives from Wild Cane Cay, Belize. In *Archaeometry '88: Proceedings from the 1988 International Archaeometry Conference,* edited by R. M. Farquar, R. J. V. Hancock, and L. A. Pavlish, pp. 255–260. University of Toronto, Toronto.

Moholy-Nagy, H.

1999 Mexican Obsidian at Tikal, Guatemala. *Latin American Antiquity* 10:300–313.

Moholy-Nagy, H., and F. W. Nelson

1990 New Data on Sources of Obsidian Artifacts from Tikal, Guatemala. *Ancient Mesoamerica* 1:71–80.

Nelson, F. W.

1980 Rutas de intercambio en la península de Yucatán en las diferentes epocas arqueológicas según la evidencia de la obsidiana. In *XVI Mesa Redonda,* vol. 1., pp. 349–355. Sociedad Mexicana de Antropología, Saltillo, Mexico.

1985 Summary of the Results of Analysis of Obsidian Artifacts from the Maya Lowlands. *Scanning Electron Microscopy* II:631–649.

1989 Rutas de intercambio de obsidiana en el norte de la península de Yucatán. In *La obsidiana en Mesoamérica,* edited by M. Gaxiola G. and J. E. Clark, pp. 363–368. Instituto de Antropología e Historia, Mexico.

Pires-Ferreira, J. W.

1975 *Formative Mesoamerican Exchange Networks with Special Reference to the Valley of Oaxaca.* Memoirs of the Museum of Anthropology, No. 7. University of Michigan, Ann Arbor.

1976 Obsidian Exchange in Formative Mesoamerica. In *The Early Mesoamerican Village,* edited by K. V. Flannery, pp. 292–306. Academic Press, New York.

Robinson, E. J.

1994 Chitak Tzak, un centro regional postclásico tardío de los mayas Kaqchikel. In *VII simposio de investigaciones arqueológicas en Guatemala, 1993,* edited by J. P. Laporte and H. Escobedo, pp.175–184. Museo Nacional de Arqueología y Etnología, Guatemala.

1997 Protohistoric to Colonial Settlement Transition in the Antigua Valley, Guatemala. In *Approaches to the Historical Archaeology of Mexico, Central & South America,* edited by J. Gasco, G. C. Smith, and P. Fournier-García, pp. 59–70. Monograph No. 38, the Institute of Archaeology. University of California, Los Angeles.

Sánchez Polo, R.

1991 *Las navajas de obsidiana de Kaminlajuyú/San Jorge: un estudio tecnológico funcional.* Unpublished licenciatura thesis, Escuela de Historia, Área de Arqueología, Universidad de San Carlos Borromeo de Guatemala, Guatemala.

Seelenfreund, A., C. Rees., R. Bird, G. Bailey, R. Bárcena, and V. Durán.

1996 Trace-Element Analysis of Obsidian Sources and Artifacts of Central Chile (Maule River Basin) and Western Argentina (Colorado River). *Latin American Antiquity* 7:7–20.

Sidrys, R. V.

1976a Classic Maya Obsidian Trade. *American Antiquity* 41:449–464.

1976b *Mesoamerica: An Archaeological Analysis of a Low-Energy Civilization.* Ph.D. dissertation, Department of Anthropology, University of California, Los Angeles. University Microfilms, Ann Arbor.

1977 Mass-Distance Measures for the Maya Obsidian Trade. In *Exchange Systems in Prehistory,* edited by T. K. Earle and J. E. Ericson, pp. 91–108. Academic Press, New York.

Stross, F. H., P. D. Sheets, F. Asaro, and H. V. Michel

1983 Precise Characterization of Guatemalan Obsidian Sources, and Source Determination of Artifacts from Quirigua. *American Antiquity* 48:323–346.

Stross, F. H., J. R. Weaver, G. E. A. Wyld, R. F. Heizer, and J. A. Graham

1968 Analysis of American Obsidians by X-Ray Fluorescence and Neutron Activation Analysis. *Contributions of the University of California Archaeological Research Facility* 5:59–79.

Torrence, R.

1986 *Production and Exchange of Stone Tools: Prehistoric Obsidian in the Aegean.* Cambridge University Press, Cambridge.

Trombold, C. D., J. F. Luhr, T. Hasenaka, and M. D. Glascock

1993 Chemical Characteristics of Obsidian from Archaeological Sites in Western Mexico and the Tequila Source Area: Implication for Regional and Pan-Regional Interaction within the Northern Mesoamerican Periphery. *Ancient Mesoamerica* 4:255–270.

Washington, H. S.

1921 Obsidian from Copán and Chichén Itzá. *Journal of the Washington Academy of Sciences* 11:481–487.

Weaver, J. R., and F. H. Stross

1965 Analysis by X-Ray Fluorescence of Some American Obsidians. *Contributions of the University of California Archaeological Research Facility* 1:89–93.

Zeitlin, R. N.

1982 Toward a More Comprehensive Model of Interregional Commodity Distribution: Political Variables and Prehistoric Obsidian Procurement in Mesoamerica. 47:260–275.

Notes

1. To a great degree, this is because the vast majority of Maya obsidian comes from just four sources: El Chayal, Ixtepeque, San Martín Jilotepeque, and Pachuca. The last long has been recognized for its golden-green hue, though the others often are lumped together as "gray" obsidian. Together, these four sources account for 98 percent or more of most Maya assemblages, with the important exceptions of some collections from the northern lowlands (Andrews et al. 1989; Braswell 1997b, 1998, 2000), the northwest periphery (Lewenstein and Glascock 1997), and Soconusco and the western Maya highlands (Clark et al. 1988). Elsewhere in the Maya area, visual sourcing consists of distinguishing among the three principal Guatemalan sources, and identifying the occasional to rare artifact from other Mexican, Honduran, or minor Guatemalan sources.

2. The quarry zone of San Bartolomé Milpas Altas is located just 9 km east of Chitak Tzak, but raw material from this source area is largely unsuitable for use in prismatic blade and biface production. Prehispanic residents of the region used San Bartolomé obsidian only rarely for making ad hoc flake tools.

3. An additional artifact was analyzed by XRF but could not be assigned to a source because of measurement errors caused by the thinness of the sample (Guderjan et al. 1989:Table 2).

4. See McKillop and Jackson (1988) for a discussion of the effects of small sample-size on models of Maya obsidian exchange.

Received November 29, 1999; accepted March 4, 2000; revised April 10, 2000.