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Fred H. Stross, Payson Sheets, Frank Asaro, and
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January 1981

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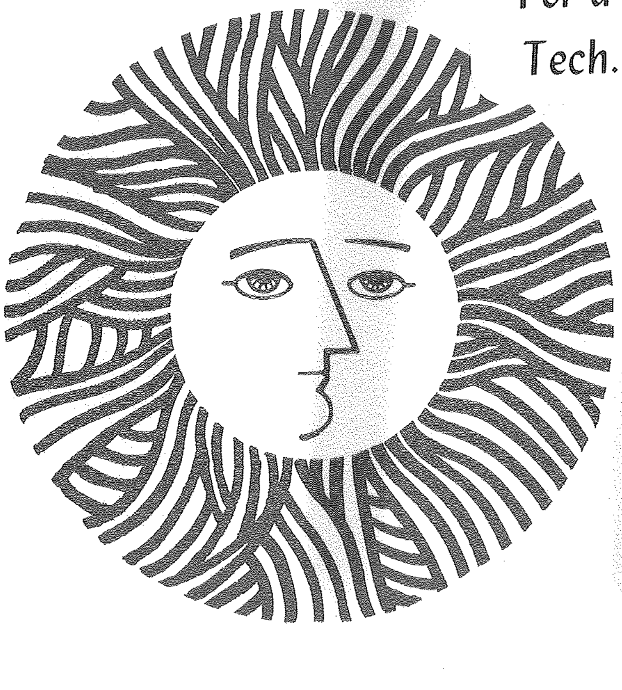

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PRECISE CHARACTERIZATION OF GUATEMALAN OBSIDIAN SOURCES, AND SOURCING OBSIDIAN ARTIFACTS FROM QUIRIGUÁ

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In the determination of provenience of obsidian artifacts, precise and accurate measurements of composition patterns of the geologic sources are necessary for definitive and cost-effective assignments. Intercomparsion is often difficult. Suggestions for maximizing the usefulness of data already in the literature are made, contributions to a useful data bank of source composition patterns are recorded, and provenience determinations of thirty artifacts excavated in Quiriguá, Guatemala, are presented to exemplify the technique.

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INTRODUCTION

During the past fifteen years, the study of composition patterns of obsidians has proven highly useful in establishing the course of supply routes and trade networks in Mesoamerica as well as elsewhere. (Cobean et al. 1971; Heizer et al. 1965; Renfrew et al. 1966; Stross et al. 1976). A prime requirement in this work has been to provide accurate and detailed information on the regional sources of the obsidian; their extent and composition, their homogeneity, or lack of it, and the location of the individual outcrops of which a source or source area may be composed. These features have often turned out to be far more complex and extensive than originally imagined, and this paper is intended to provide additional information on some of of the more important Mesoamerican source areas, specifically those in southern Guatemala.

There does not, at present, appear to to be any strict delimitation of the concept of source area. The compositions recorded in this paper will be designated, in accord with usage adopted in the literature, with a recognizable geographic context. The sources discussed are located in southern Guatemala. (Appendix A) They include those previously referred to as San Martin Jilotepeque, Rio Pixcayá, and Aldea Chatalun, all in the department of Chimaltenango; a source in Sacatepéquez, referred to as San Bartolomé Milpas Altas; a source in Santa Rosa by the Laguna de Ayarza, referred to as Media Cuesta; one in Jalapa, referred to as Jalapa; and a possible source in the department of El Progreso, by the Puente Chetunal. Their composition records may be added to the detailed records of compositions of the El Chayal, Ixtepeque, and Tajumulco sources, which already have been published (Asaro et al. 1978).

In addition to these source samples, a number of artifacts excavated in Quiriguá were also analyzed.

ANALYTICAL METHODS

Neutron Activation Analysis (NAA)

Measurements are made by precise and accurate neutron activation analyses (Perlman et al. 1969); and data are included for 21 elements. The errors shown for an individual element reflect the precision (or repeatability) of the measurements. Studies are made on specially prepared samples, and the procedures for both sample preparation and measurements are rigidly controlled. As an example: The element abundances on an artifact of Ixtepeque obsidian were found to agree within 1.7% (for the 16 most precisely measured elements) with the analysis of Ixtepeque obsidian measured 5 years earlier.

Measurements are calibrated with the standard "Standard Pottery". The element abundances of the latter were determined by using primary standards, and their values and errors have been published (Perlman et al. 1969). The accuracy for a particular element, which is usually close to the precision, may be determined (expressed in per cent) by taking the square root of the sum of the squares of the precision (expressed in per cent) and the accuracy (Perlman et al. 1971) of that element in Standard Pottery (expressed in per cent).

X-ray fluorescence (XRF)

This type of measurement can be carried out with high precision and accuracy (Giauque et al. 1977). The present work on artifacts, however, was not done in this manner, as the emphasis was on non-destructive measurements, and on lowest possible cost. The accuracy of the latter measurements was approximately 10 to 15%, and with some additional effort accuracies of 6% or better should be attainable.

When comparing data measured against the same standard, as in the NAA measurements, precision can be used to indicate the extent of agreement. When comparing data measured against different standards, the accuracy should be used to test the agreement.

General procedure (Artifacts)

Artifacts are first measured by XRF with a ^{109}Cd source (for Rb, Sr, and Zr) and then with a ^{241}Am source (for Ba). The artifacts are divided into chemical groups from these measurements, although other elements determined by the XRF (Fe, Mn, Zn, Y, and Nb) are sometimes used if their abundances are unusually high. Representative members of each chemical group, and any samples not falling into a group, are analyzed destructively by an abbreviated NAA sequence for Mn, Na, Dy, K, and Ba. The number of artifacts for which this is necessary is approximately 10-15% of those analyzed by XRF. These measurements must conform nearly exactly to a known group before source assignments are made. For any sample that does not conform to a known group by the abbreviated NAA sequence, the NAA sequence is completed for all of the elements shown in Table 2. Generally, 10 to 15% of the samples undergoing an abbreviated NAA sequence would need to have the NAA completed. All members of chemical groups determined by XRF, whose representative members conform exactly with a known source by the abbreviated NAA sequence, are assigned to that source. Any artifacts of uncertain origin will have had a complete NAA sequence and will _a priori_ represent a new source or a new variation in a known source.

Laboratory intercalibration

A number of laboratories (Asaro et al. 1978, Cobean et al. 1971, Hurtado de Mendoza 1978, Zeitlin et al. 1978, Jack et al. 1968) have made chemical measurements on obsidian from Mesoamerican sources primarily by NAA and XRF. It is often difficult for one laboratory to use the source data of another for many reasons, among which are the following: abundances are sometimes only given in terms of counting rates of gamma or x-rays; corrections are not made for background or interfering radiations; measurements are calibrated against different standard materials, or measurement errors are made. The best solution would be for all laboratories that study obsidian source material to make accurate measurements against the same standard or against different but well-known standards. When this is not feasible it is possible to intercalibrate those laboratories, which make reproducible, but not necessarily accurate measurements. Intercalibration of two laboratories does not imply that the results of one laboratory are better than those of the other. It is simply a way of relating the experimental results to each other. The LBL measurements by NAA have been intercalibrated with those of Ericson and Kimberlin

(1977) and Hurtado de Mendoza and Jester (1978). Our XRF data have been intercalibrated with Zeitlin and Heimbuch (1978) and with Cobean et al. (1971). The intercalibration formulas are given in footnotes to the Tables. The complexity of the XRF intercalibration arises because backgrounds sometimes are not subtracted from the peaks, nor interferences removed.

RIO PIXCAYÁ

The Rio Pixcayá, Chimaltenango, source area represents a complex series of deposits. Some of the known deposits are difficult to reach, and the samples available for analysis in this work were collected by different individuals at different times, from different geographic and geologic contexts. The region from which samples were obtained lies within the triangle formed by the towns of Chimaltenango, Choatalum ("Aldea Chatalun" of Cobean et al. 1971), and Comalapa, in the department of Chimaltenango (Fig. 1). This source area is of particular interest because it was used nearly 12,000 years ago (Stross et al. 1977), although in later times it appears to have played a smaller role than the great deposits of El Chayal and Ixtepeque.

Fox, in his ethnohistoric volume Quiché Conquest (1978), reports finding a major obsidian outcrop at the prehistoric site of Chuisac, two kilometers west of San Martín Jilotepeque. Chuisac may have been a major obsidian and manufacturing trading center. Both chemical analyses of obsidian and technological analyses of workshops are urgently needed from this locality. It is not known if this obsidian relates to the Rio Pixcayá group.

In Table 1 are shown XRF data on 22 specimens collected by one of us (P.S.) from the department of Chimaltenango and also XRF data of other workers. Table 2 shows NAA data of representative members of each group and recalibrated data of other workers. It also includes unpublished data of Sidrys et al. (n.d.) on obsidian from the Finca Durazno, and previously published data on obsidian collected at a road cut. From the Finca Durazno in the south (Sidrys et al. 1976), near Chimaltenango, to "Dulce Nombre" in the north, the collected obsidian forms a chemically homogeneous group, which probably also includes obsidian from the nearby village Chatalun or Choatalum. The measurements on Aldea Chatalun obsidian were made by others (Cobean et al. 1971) and cannot be directly compared with our work. Recalibrated values for Aldea Chatalun obsidian, however, are shown in Table 1. These are roughly consistent with the main group just discussed. Obsidian collected at "Sauces" and "Las Burras", which are located near Choatalum, are somewhat different in composition, and readily distinguishable by both XRF and NAA methods, as seen in Table 1 and 2.

The measurements by Zeitlin and Heimbuch (1978) on "Jilotepeque" obsidian (San Martín Jilotepeque) agree most closely with the Las Burras group. The source of the "Jilotepeque" obsidian could not be ascertained from their publication.

The measurements by Hurtado de Mendoza and Jester (1978) on San Martín Jilotepeque obsidian agree most closely with the Sauces group, also shown in Table 2.

Nearly all source obsidian labeled Rio Pixcayá or Pixcayá appears to be of the same composition regardless of who collected or measured the obsidian. Most artifacts from distant areas which have been assigned a provenience of S.M.J. or Pixcayá have this composition profile. Thus, the "Representative Rio Pixcayá" obsidian, as analyzed by XRF as well as NAA and presented in Table 2, includes material from Dulce Nombre, Rio Pixcayá alluvium, Finca Durazno, Buena Vista, Outcrop 3-1, and Choatalum. One "source" sample collected from alluvial gravel in the Rio Pixcayá by one of the authors (P.S.) had a different profile, as shown in Tables 1 and 2, and its primary source is not known. Obsidian collected from S.M.J. and the region north and northeast exhibited two other composition patterns besides that of the Rio Pixcayá, as shown in Tables 1 and 2.

The Rio Pixcayá analyses furnish a good example of the problems in defining the concept of "obsidian source". While unworked as well as worked obsidian is abundant at the Finca Durazno site and it is cited as a source by some authors (e.g. Sidrys et al. 1976), it does not have common characterisitics of geologic flow or outcrop, We may call it a "secondary" source to include the possibility, that substantial transport or unworked material by such agencies as flooding or volcanic eruption could have removed obsidian from its "primary", or original geologic source to its present area.

Another problem results from the analysis of Las Burras and Sauces material. The data, while clearly distinguishable from "Representative Rio Pixcayá", are still more similar to this pattern (i.e. they have a lower average difference between the individual elements) than more remote sources. This feature has been observed in the study of a number of other source areas at their peripheries (Asaro et al. 1978) and the questions of how to associate or to separate such material from the more abundant "main" group, and where and how to draw the line between the different "source areas" (so called for convenience), are not resolved.

SAN BARTOLOMÉ MILPAS ALTAS

The source area of San Bartolomé Milpas Altas, Sacatepéquez, is even less well understood than that of Rio Pixcayá. There have even been questions as to its existence (Sidrys et al. 1976). Recently, several kilograms of obsidian were collected on the Finca Nimachay, located in the immediate vicinity of the village of San Bartolomé Milpas Altas. Table 3 gives the detailed analysis of a sample from the Finca Nimachay.

Measurements of source material from San Bartolomé Milpas Altas have been reported (Cobean et al. 1971), Hurtado de Mendoza et al. 1978, Zeitlin et al. 1978). The data by Cobean et al. (1971) and Zeitlin et al. (1978) were intercalibrated with the data obtained at Lawrence Berkeley Laboratory (LBL) and agree as well as could be expected, as shown in Table 3. Although the data of Stross et al. (1976) on many elements were intercalibrated with LBL NAA data, Zr was not one of the elements. Thus, the Zr discrepancy may be simply a calibration problem.

The various measurements by different laboratories and techniques of obsidian from the vicinity of San Bartolomé Milpas Altas give similar abundances when intercalibrated. Thus, the source undoubtedly exists. The abundances shown for Finca Nimachay in Table 3 may be taken as representative of San Bartolomé Milpas Altas composition group.

LAGUNA DE AYARZA

The Laguna de Ayarza is located about 50 kilometers southeast of Guatemala City by a straight line. On the north shore of the lake is the village of Media Cuesta; a nearby obsidian outcrop with the same name has been mentioned in the literature (Stross et al. 1976, Zeitlin et al. 1978). Another outcrop is located 5 kilometers west of Media Cuesta, between Sabana Redonda and the Rio Los Vados, on the road to Media Cuesta.

Five samples from Media Cuesta were analyzed by XRF. Three of these were found to have similar compositions, the other two differed from this group, and among themselves. One sample from the group of three was analyzed by a complete NAA sequence and one of the other two by an abbreviated NAA sequence. These NAA analyses have confirmed the results obtained by XRF. The analytical results relating to this area are recorded in Tables 4 and 5. This source has not been represented much in artifactual material analyzed so far.

Few analytical data for this source are available in the literature. Those given by Cobean et al, and by Zeitlin et al. are shown in Table 5 for comparison, after having been modified as mentioned above.

JALAPA

The Jalapa source is located east of Guatemala City, about 60 kilometers by air. In spite of its good quality for tool manufacture, the obsidian from this source does not appear to have been widely distributed in pre-Conquest times. The results of NAA and of XRF analyses are given in Table 6.

PUENTE CHETUNAL

The Puente Chetunal, El Progreso, is a bridge of the Carretera Interoceanica (CA9) over the Motagua River, just south of the road junction leading to Cobân, approximately

83 kilometers NE of Guatemala City.

Some years earlier some samples had been collected from alluvial gravel in the river by one of the authors (F.H.S.), and subsequently analyzed. Four samples formed a coherent group, and one sample was much different (the average difference of the abundances of the elements from those of the group was 12%). The results of neutron activation analysis are shown in Table 7. In 1979 the site was visited again. No obsidian was found in the river this time, but obsidian rock was found embedded in rock about 30 to 50 meters west of and on the same level as the bridge (approximately) 20 meters above the river). One of the samples secured from rock outcrop was analyzed by NAA and by XRF. The results of are shown in Table 7 also. The composition matches neither the group of four, not the "odd" sample anayzed earlier, but it is remarkably close to that of El Chayal obsidian previously reported (Asaro et al. 1978), the average difference in the abundances of the 16 best measured elements by NAA being only 2.1%. Puente Chetunal is about 60 kilometer down-drainage from El Chayal. The deposit could not be studied in detail, and the possibility that this "outcrop" is a secondary source as defined above cannot be excluded.

It is not known if the earlier samples, found in the river, had washed from another nearby outcrop or from further upriver.

QUIRIGUÁ ARTIFACTS

The analyses described so far were made on unworked samples and were intended to characterize obsidian sources. In addition, a group of thirty artifacts excavated in Quiriguá were analyzed in order to determine their provenience. Quiriguá is a relatively compact Maya site a little over 200 kilometers northeast of Guatemala City. Initially it was an important satellite of the great Maya center of Copân, but it achieved independence by the mid-8th century A.D. (Sharer 1978). The most extensive excavations to data have been conducted by the University Museum of Pennsylvania jointly with the Government of Guatemala since 1973, and it is these excavations that yielded the samples here described.

The thirty samples were analyzed by XRF, and seven of these were also analyzed by the abbreviated NAA sequence for additional information. On the basis of these analyses, recorded in Table 8, 24 artifacts would be assigned a provenience from Ixtepeque, and four artifacts from El Chayal. These results fit the model proposed by Hammond (1972). Two samples (QUIR22 and QUIR24) could not be positively identified by the method indicated and a complete NAA sequence was carried out on these samples

As a result of the more detailed NAA experiments, one of the two unidentified samples (QUIR22) agreed very closely with the average composition of the El Chayal source, and it is assigned to that primary source (the average difference for the 16 best measured elements was 2.5%). It agreed, however, even more closely (1.5%) with the composition of the sample collected at the Puente Chetunal (Table 7). This would be of distinct interest if the Puente Chetunal deposit is verified as a separate (primary) source: this deposit is about 120 kilometers from Quiriguá, while El Chayal is about 180 kilometers distant, all by present roads. Table 8c shows the analytical results of the artifact in question (QUIR22) and of the source samples with which it is compared. It also shows the results for the remaining unidentified sample (QUIR24). The latter vaguely resembles the El Chayal composition pattern (average difference of 7.8% for the 16 best measured elemets). QUIR 24 is better correlated with the "odd" Puente Chetunal sample (Table 7), but even there the agreement was not very close (average difference = 3.8%).

Three of the four Quiriguá obsidian artifacts attributed to the El Chayal source had alluvial (stream cobble) cortex on them, and they were part of a cottage industry which provided rural residents an alternative source of cutting tools to the core-blade technology of central Quiriguá. Rural stoneworkers obtained fist-sized to lemon-sized nodules of obsidian from alluvial gravels, probably along the Motagua river not too far from Quiriguá. Quiriguá is located about 180 kilometers down drainage from El Chayal. One of us (P.S.) has found unworked (non-artifactual) obsidian in present gravels within 2 kilometers of Quiriguá, but the location of alluvial sources for the Classic Period is unknown. The rural stoneworker would create cutting flakes by an informal percussion technique, making frequent errors and creating much wastage. If a source were close, such waste would not be as uneconomic as if the obsidian had to be transported by people from El Chayal. Thus, 3/4 of the El Chayal obsidian in the sample should not be interpreted as demonstrating trade from El Chayal to Quiriguá.

One of the four Quiriguá artifacts attributed to El Chayal was a prismatic blade, and this probably does indicate a trade relationship. Large nodules are necessary for core-blade manufacture, and these occur at the El Chayal locality. During the Classic Period most long-distance traded obsidian was in the form of macrocores, as the initial stages of manufacture were performed at or near the quarry. Prismatic blades generally were manufactured at the sites where they were used.

Notable is the almost complete lack of non-Guatemalan obsidian at Quiriguá. No obsidian from sources outside Guatemala was detected in the samples analyzed in this study. These were taken from a larger collection of 7039 obsidian artifacts from excavations and surface collections made by Quiriguá Project staff since 1975. One of us (P.S.) analyzed these artifacts, and found a total of four specimens of green obsidian. Green obsidian in the past has been found to derive from Pachuca, Hidalgo, Mexico, and none of these were submitted for analysis. One specimen was a fragment of a small, bifacially-flaked projectile point, and the other three were prismatic blades. The former was found in the site center, and the blades were found at Locus 99, a relatively small site across the Motagua River from Quiriguá, 4 km from the site center. Thus, only 0.06% of Quiriguá's obsidian is thought to have come from Mexican sources. This is very similar to Chalchuapa, where only 20 out of 40,000 obsidian artifacts were of green obsidian, or 0.05%. Tikâl, for comparison, has about 2% green obsidian (Moholy-Nagy, pers. comm. 1980). These differences are at least partly explained by proximity and by trade routes dominated during the Early and Middle Classic Periods by Teotihuacan.

The well-documented southward movement of Chortî Maya from northern Guatemala and Belize during the 5th and 6th centuries (Thompson 1970) may have been motivated, at least in part, by a need to control access to obsidian. Teotihuacân, already in control of the Mexican obsidian trade into the Maya area, established a stronghold at Kaminaljuyû, near the large El Chayal source. The major part of the Teotihucân presence lasted from about AD 450 to 600 (Cheek 1977). The Teotihucân move into Kaminaljuyû may have been perceived by the lowland Maya as an attempt to establish a Mesoamerican monopoly on obsidian. Thus, a migration to colonize the southeastern Maya highlands surrounding the huge obsidian deposits at Ixtepeque, also including the Media Cuesta source, would break the threatened monopoly. That the majority of analyzed obsidian at Tikâl derived from Ixtepeque, with some from El Chayal, and a few from Mexican sources, tends to support the hypothesis that the Chortî were moving southward for obsidian. Likewise the fact that so little Quiriguá obsidian evidently derived from Mexican sources, and that Ixtepeque dominates the sample, also tends to support the hypothesis.

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TABLE 1

ELEMENT ABUNDANCES OF CHIMALTENANGO - OBSIDIAN MEASURED BY X-RAY FLUORESCENCE $^{1),2)}$

					Other Composition Groups			Other Workers			
Location:	Rio Pixcaya Riverbed	Dulce Nombre	Buena Vista	Representative Rio Pixcaya	Sauces	Las Burras	Odd Sample From Rio Pixcaya Riverbed	Aldea Chatalun		Jilotepeque	Rio Pixcaya
								Z & H$^{3)}$ (Revised)	Cobean$^{4)}$ (Revised)	Z & H$^{3)}$ (Revised)	Jack$^{5)}$
No. of samples	4	5	5	14	2	5	1				
Element											
Rb	118 ± 6	115 ± 7	116 ± 6	116 ± 6	120 ± 7	106 ± 6	123 ± 6	127 ± 8	112	118 ± 11	129
Sr	189 ± 4	192 ± 9	188 ± 6	190 ± 6	191 ± 5	225 ± 11	93 ± 3	199 ± 15	190	202 ± 8	175
Zr	113 ± 3	117 ± 3	114 ± 3	115 ± 3	137 ± 3	183 ± 8	152 ± 3	111 ± 14	116	180 ± 14	105
Rb/Zr	1.04 ± .06	.98 ± .07	1.02 ± .04	1.01 ± .05	.88 ± .06	.58 ± .04	.81 ± .04	1.14 ± .16	∿ .97	.66 ± .08	1.23
Sr/Zr	1.67 ± .06	1.64 ± .08	1.65 ± .06	1.65 ± .06	1.39 ± .05	1.23 ± .08	.61 ± .02	1.79 ± .26	∿1.64	1.12 ± .10	1.67
Mn								496 ± 50		561 ± 56	515
Comment:										Like Las Burras	

TABLE 2

ELEMENT ABUNDANCES OF CHIMALTENANGO OBSIDIAN MEASURED BY NEUTRON ACTIVATION ANALYSIS[1] IN THE PRESENT WORK

					Other workers		
					Hurtado de Mendoza et al[7]		Jack[5]
					NAA	NAA	XRF
	Representative[6] Rio Pixcayá	Las Burras	Sauces	Odd Sample From Rio Pixcayá Riverbed	San Martin Jilotepeque	Pixcayá	Rio Pixcayá
No. of Samples	8	1	1	1	4	4	1
Al%	7.03 ± 0.23						
Ba	1105 ± 32	1179 ± 34	1110 ± 37	1074 ± 31			1000
Ce	47.5 ± 0.3	51.8 ± .7	47.1 ± .06		47	48	∿40
Co	0.33 ± 0.6	0.57 ± .05	.63 ± .05				
Cs	3.37 ± 0.12	2.24 ± .06	3.70 ± .08		4.2	3.8	
Dy	2.03 ± 0.10	2.49 ± .12	2.42 ± .15	3.35 ± .09			
Eu	0.543 ± 0.10	.708 ± .009	.594 ± .010				
Fe%	0.655 ± 0.018	.899 ± .011	.758 ± .010		.78	.65	.65
Hf	3.21 ± 0.10	4.71 ± .07	3.65 ± .06				
K%	3.54 ± 0.25	3.26 ± .35	3.18 ± .34	3.24 ± .31			3.4
La	26.3 ± 0.5	27.1 ± .5	26.1 ± .5				∿25
Mn	521 ± 10	626 ± 6	589 ± 6	554 ± 6			
Na%	2.94 ± 0.05	3.33 ± .03	3.15 ± .03	3.42 ± .03			
Rb	122 ± 6	118 ± 5	118 ± 4		120	115	129
Sb	0.37 ± 0.05	.31 ± .04	.46 ± .06				
Sc	1.99 ± 0.03	2.031 ± .020	2.112 ± .021		2.12	1.99	
Sm	2.69 ± 0.03	3.170 ± .032	2.876 ± .028				
Ta	0.757 ± 0.008	.683 ± .007	.751 ± .008				
Th	9.24 ± 0.12	7.33 ± .07	9.21 ± .09		9.6	9.4	∿5
U	2.81 ± 0.05	2.264 ± .028	3.010 ± .033				
Yb	1.403 ± 0.025	1.759 ± .029	1.676 ± .025				
Comment:					Like Sauces	Like Representative Rio Pixcayá	Like Representative Rio Pixcayá

TABLE 3

ELEMENT ABUNDANCES OF OBSIDIAN FROM SAN BARTOLOME MILPAS ALTAS IN SACATEPEQUEZ1)

	Finca Nimachay (this work) NAA8)	Stross et al - 1976 XRF	Zeitlin & Heimbuch (Revised) XRF3)	Cobean (Revised)4) XRF	Finca Matilandia Hurtado de Mendoza & Jester (Revised)7) NAA
Al(%)	6.71 ± .10				
Ba	1150 ± 33	1100			
Ce	42.2± .5	∿40			44
Co	.62 ± .05				
Cs	3.43 ± .07				3.7
Dy	2.15 ± .08				
Eu	.523 ± .009				
Fe(%)	.828 ± .011	.84			.78
Hf	4.09 ± .06				
K(%)	3.48 ± .23	3.17			
La	21.57 ± .4	∿20			
Mn	516 ± 3	535	493 ± 40	∿465	
Na(%)	3.15 ± .06				
Rb	139 ± 5	115	132 ± 11	∿128	131
Sb	.25 ± .04				
Sc	2.258 ± .023				2.20
Sm	2.525 ± .025				
Sr	128 ± 4 XRF2)	115	132 ± 8	∿125	
Ta	.593 ± .006				
Th	9.77 ± .10	∿15			10.3
U	3.22 ± .04				
Yb	1.649 ± .024				
Zr	149 ± 4 XRF2)	125	153 ± 12	∿144	

TABLE 4

ELEMENT ABUNDANCES OF MEDIA CUESTA MAIN OBSIDIAN GROUP AND DEVIANT SAMPLE 1),2)

Number of Samples	1	1
	NAA	NAA 9)
Ba	980 ± 31	
Ce	51.4 ± 0.7	
Co	0.22 ± 0.04	
Cs	3.11 ± 0.10	
Dy	3.02 ± 0.15	3.29 ± 0.14
Eu	0.708 ± 0.010	
Fe%	0.937 ± 0.011	
Hf	4.48 ± 0.07	
K%	2.95 ± 0.30	3.50 ± 0.40
La	25.1 ± 0.7	
Mn	790 ± 8	995 ± 10
Na%	3.44 ± 0.03	3.83 ± 0.04
Rb	120 ± 5	
Sb	0.20 ± 0.04	
Se	1.84 ± 0.02	
Sm	3.45 ± 0.03	
Ta	0.758 ± 0.008	
Th	8.12 ± 0.08	
U	2.44 ± 0.03	
Yb	2.22 ± 0.03	
	XRF 2) (3 samples)	
Sr	177 ± 4	
Zr	169 ± 3	
Rb/Zr	0.70 ± 0.03	
Sr/Zr	1.05 ± 0.03	

TABLE 5

ELEMENT ABUNDANCES OF LAGUNA DE AYARZA (MEDIA CUESTA) OBSIDIAN MEASURED BY X-RAY FLUORESCENCE

	This Work[2]					Cobean (Revised)[4]	Z & H (Revised)[3]
Rb	120 ± 6	120 ± 6	113 ± 6	123 ± 6	125 ± 6	117	130 ± 7
Sr	180 ± 4	176 ± 4	176 ± 4	94 ± 3	100 ± 3	168	179 ± 10
Zr	169 ± 3	168 ± 3	169 ± 3	128 ± 3	160 ± 3	147	145 ± 12
Rb/Zr	0.71 ± 0.04	0.71 ± 0.04	0.67 ± 0.04	0.96 ± 0.05	0.78 ± 0.04	0.80	0.90 ± 0.09
Sr/Zr	1.07 ± 0.03	1.05 ± 0.03	1.04 ± 0.03	0.73 ± 0.03	0.63 ± 0.02	1.14	1.23 ± 0.12

TABLE 6

Element abundances of Jalapa obsidian1)

	This work NAA	Cobean (Revised)4) XRF	Zeitlin et al.3) (Revised) XRF	Hurtado de Mendoza et al.7) (Revised) NAA
	1 sample			
Ba	834 ±29			
Ce	55.1 ± 0.8			
Co	0.57 ± 0.06			
Cs	8.53 ± 0.18			
Dy	2.78 ± 0.08 10)			
Eu	0.736± 0.111			
Fe,%	0.854± 0.016			
Hf	3.39 ± 0.06			
K,%	3.70 ± 0.26 10)			
La	27.7 ± 0.7			
Mn	510 ± 5 10)			
Na,%	2.18 ± 0.03 10)			
Rb	167 ± 6	155	159 ±14	175
Sb	0.46 ± 0.06			
Sc	3.14 ± 0.03			3.09
Sm	3.53 ± 0.03			
Ta	0.900± 0.009			
Th	11.85 ± 0.17			11.7
U	3.78 ± 0.04			
Yb	1.72 ± 0.03			
	XRF 4 samples			
Sr	182 ± 5	180	176 ±10	
Zr	114 ± 3	124	110 ± 9	
Rb/Zr	1.46 ± 0.07	∿1.25	1.45± 0.17	
Sr/Zr	1.60 ± 0.06	∿1.45	1.60± 0.20	

TABLE 7

Element abundances of Puente Chetunal obsidian[1]

	Riverbed samples		Bank outcrop
# of samples	4	1	1
		Neutron Activation Analysis	
Al	6.95 ± .22	6.72 ± .24	6.82 ± .11
Ba	925 ±26	909 ±17	937 ±28
Ce	41.9 ± .9	45.52 ± .57	46.49 ± .64
Co	.76 ± .06	.18 ± .04	.28 ± .05
Cs	6.43 ± .20	7.00 ± .20	7.78 ± .17
Dy	2.19 ± .10	2.69 ± .09	2.48 ± .09
Eu	.486 ± .007	.587± .009	.605± .01
Fe,%	.75 ± .02	.55 ± .02	.62 ± .01
Hf	3.42 ± .15	3.16 ± .06	3.33 ± .06
K,%	3.34 ± .26	3.52 ± .25	3.40 ± .24
La	22.65 ± .59	22.92 ± .59	24.06 ± .80
Mn	450 ± 9	587 ±12	640 ±13
Na, %	2.80 ± .06	2.98 ± .06	3.21 ± .06
Rb	138 ± 4	148 ± 4	159 ± 6
Sb	.67 ± .08	.55 ± .06	.63 ± .06
Sc	2.27 ± .02	1.64 ± .02	1.83 ± .02
Sm	2.46 ± .03	2.98 ± .03	2.98 ± .03
Ta	.931 ± .009	.965± .005	.927± .006
Th	11.07 ± .11	11.15 ± .11	10.53 ± .11
U	4.32 ± .04	4.89 ± .05	4.32 ± .04
Yb	1.561 ± .024	2.010± .026	1.91 ± .03
		X ray Fluorescence[2]	
Sr			170 ±6
Zr			125 ±5
Rb/Zr			1.27± .07
Sr/Zr			1.36± .07

TABLE 8a

QUIRIGUÁ ARTIFACTS AND GUATEMALAN SOURCES COMPARED BY X-RAY FLUORESCENCE

	Quiriguá samples	El Chayal source	Quiriguá samples	Ixtepeque source	QUIR 22	QUIR 24
# of samples	4		24	6	1	1
Ba	898±26	915±35	980±76	1030±27	∿871	∿876
Ce	51.5±6.6	46.7±.9	42.0±3.5	43.3±0.9	47.6±6.1	43.8±5.6
Rb/Zr	1.27±0.04	1.24±0.04	0.58±0.01	0.57±0.01	1.37±.04	1.67±.06
Sr/Zr	1.29±0.04	1.29±0.04	0.88±0.02	0.90±0.02	1.37±.04	1.60±.05

TABLE 8b

CONFIRMATION OF XRF SOURCE ASSIGNMENTS OF QUIRIGUÁ ARTIFACTS BY AN ABBREVIATED NAA SEQUENCE

	Quiriguá artifacts	El Chayal source	Quiriguá artifacts	Ixtepeque source
# of samples	2	27	4	6
Ba	865±84	915±35	1030±54	1030±27
Dy	2.72±0.16	2.66±0.11	2.32±0.14	2.30±0.11
K%	2.90±0.29	3.45±0.26	3.81±0.30	3.61±0.26
Mn	646 ±13	649 ±13	449 ±9	449 ±9
Na%	3.22±0.02	3.15±0.06	3.06±0.03	3.05±0.05

TABLE 8c

Quiriguá artifacts and sources compared by complete sequence neutron activation analysis

	Quiriguá artifact QUIR 22	Puente Chetunal Bank outcrop	El Chayal Average Asaro et al. 1978 & Sidrys et al., n.d.	Quiriguá artifact QUIR 24	Puente Chetunal "odd" riverbed
Al	6.92 ± 0.12	6.95 ± 0.11	7.12 ± 0.16		6.72 ± 0.24
Ba	940 ±29	937 ±28	915 ±35	957 ±30	909 ±17
Ce	44.3 ± 0.6	48.1 ± 0.6	46.7 ± 0.9	44.3 ± 0.6	45.5 ± 0.6
Co	0.48 ± 0.05	0.28 ± 0.05	0.34 ± 0.13	0.33 ± 0.05	0.18 ± 0.04
Cs	7.65 ± 0.17	7.78 ± 0.17	7.65 ± 0.25	6.41 ± 0.15	7.00 ± 0.20
Dy	2.52 ± 0.09	2.48 ± 0.09	2.66 ± 0.11	2.30 ± 0.11	2.69 ± 0.09
Eu	0.598± 0.008	0.591± 0.008	0.585± 0.110	0.557± 0.009	0.587± 0.008
Fe,%	0.595± 0.013	0.621± 0.014	0.627± 0.027	0.528± 0.012	0.55 ± 0.02
Hf	3.21 ± 0.07	3.33 ± 0.06	3.27 ± 0.08	3.03 ± 0.06	2.75 ± 0.12
K,%	2.97 ± 0.23	3.40 ± 0.24	3.45 ± 0.26	3.61 ± 0.26	3.82 ± 0.25
La	24.8 ± 0.8	24.1 ± 0.08	24.6 ± 1.0	22.9 ± 0.7	22.1 ± 0.6
Mn	626 ±13	640 ±13	649 ±13	609 ±12	587 ±12
Na,%	3.14 ± 0.06	3.21 ± 0.06	3.15 ± 0.06	3.06 ± 0.06	2.98 ± 0.06
Rb	158 ± 6	159 ± 6	149 ± 8	156 ± 6	148 ± 6
Sb	0.62 ± 0.07	0.63 ± 0.06	0.74 ± 0.11	0.86 ± 0.08	0.55 ± 0.07
Sc	1.83 ± 0.02	1.83 ± 0.02	1.85 ± 0.05	1.42 ± 0.02	1.64 ± 0.02
Sm	2.97 ± 0.03	2.98 ± 0.03	3.03 ± 0.03	3.00 ± 0.03	2.98 ± 0.03
Ta	0.911± 0.009	0.927± 0.009	0.93 ± 0.02	0.957± 0.010	0.965± 0.010
Th	10.50 ± 0.10	10.53 ± 0.11	10.4 ± 0.1	11.1 ± 0.1	11.2 ± 0.1
U	4.21 ± 0.05	4.23 ± 0.04	4.33 ± 0.07	4.93 ± 0.05	4.89 ± 0.05
Yb	1.87 ± 0.03	1.91 ± 0.03	1.92 ± 0.05	2.04 ± 0.03	2.01 ± 0.03

NOTES (TABLES)

1) Abundances are given in ppm except where otherwise indicated. The errors are the counting errors or, if more than one sample, the larger of the counting error or the root-mean-square deviation.

2) In the XRF measurements there are also calibration uncertainties, ca. 10% for Rb, and Sr, and 15% for Zr.

3) In order to compare the data of Zeitlin and Heimbuch with LBL measurements, the Z & H data were modified as follows: Rb = (Z & H value) x 1.01 - 25; Sr = (Z & H value) x 1.12 - 25; Zr = (Z & H value) x 1.43 - 25. In addition, 15% of the Sr was removed from the Zr value. Mn = (Z & H value) x (0.82 ± 0.08). The errors are the maximum of the square root of the pooled sources variance given by Z & H or the root-mean-square-deviation in the calibration coefficient used to intercalibrate the two laboratories. These latter are 5%, 4%, and 8% for Rb, Sr, and Zr respectively.

4) In order to compare the data of Cobean et al. with LBL measurements, the Cobean data were modified as follows: Rb = (Cobean mean Rb) x 0.9; Zr = (Cobean mean Zr) x 1.23 - 0.15 (Cobean mean Sr). Cobean's lower Sr limits were taken as 5 rather than 30 ppm.

5) R.N. Jack's measurements, made by XRF , are included in a summary by Stross et al. 1976. Jack's values were the top of the range given for Zr and K, and the bottom of the range for Rb and Sr,. Recalibration of Jack's values is described on p. 257 of Stross et al. 1976.

6) This group includes two samples from the riverbed, four from Finca Durazno, and two from a road cut outcrop 3-1 as designated by Sidrys 1976.

7) Hurtado de Mendoza and Jester's gamma ray counting data were changed to ppm or % by multiplying their Ce, Fe, Rb, Sc (1121 Kev) and Th values by 1.79, 0.45, 0.229, 0.165 and 0.45 respectively. This calibration is crude and assumes their Cerro Chayal obsidian group to have the same composition pattern as the LBL El Chayal group (Asaro et al. 1978).

8) Except for Sr and Zr, which were measured by XRF.

9) Measurements were made by an abbreviated NAA sequence.

10) Two samples were measured which gave identical results within counting errors.

APPENDIX A

Location of sites

Locality	Latitude N	Longitude W
Source area		
Chimaltenango	clustered around 14°45'	90°50'
San Bartolomé Milpas Altas	14°36'	90°41'
Laguna de Ayarza	14°26'	90° 8'
Jalapa	14°42'	90° 2'
Puente Chetunal	14°55'	90° 1'
Quiriguá	15°17'	89° 4'

APPENDIX B

Sample Concordance

Location	XRF	NAA
Chimaltenango		
Rio Pixcayá, riverbed	8067 X-Z,1	799 S,T
Rio Pixcayá, riverbed, "odd"	8067 W	1089 K
Dulce Nombre	8068 S-W	1065 P
Buena Vista	8067 2-6	1015 F, 1061 Q
Sauces	8068 X,Y	1015 T, 1061 R, 1065 O
Las Burras	8067 7-9, 8068 Q,R	1015 G,H,J, 1030 Z
"Representative Rio Pixcayá"	8067 X-Z, 1-6, 8068 S-W	943 G, I, K-O, 799 S,T
San Bartolomé Milpas Altas	8088 F,H	1072 V
Laguna de Ayarza		
Media Cuesta	8067 $,.,], ≠,↦	1015 M,N, 1030 X
Jalapa	8067 ^, 8068 D-G	1015 O,P, 1030 Y
Puente Chetunal		
Riverbed		715 U, 727 E,F
Riverbed, "odd"		727 G
Bank outcrop	8088 G	1072 W, 1089 E,F
Quiriguá	8069 S-Z, 1-3, 5-9, +,-,*,/, $,],≠,→,^,↑,;	1022 E,F,H,J,M
QUIR 22	8069 (	1072 X, 1089 M
QUIR 24	8069 .	1022 K, 1061 T

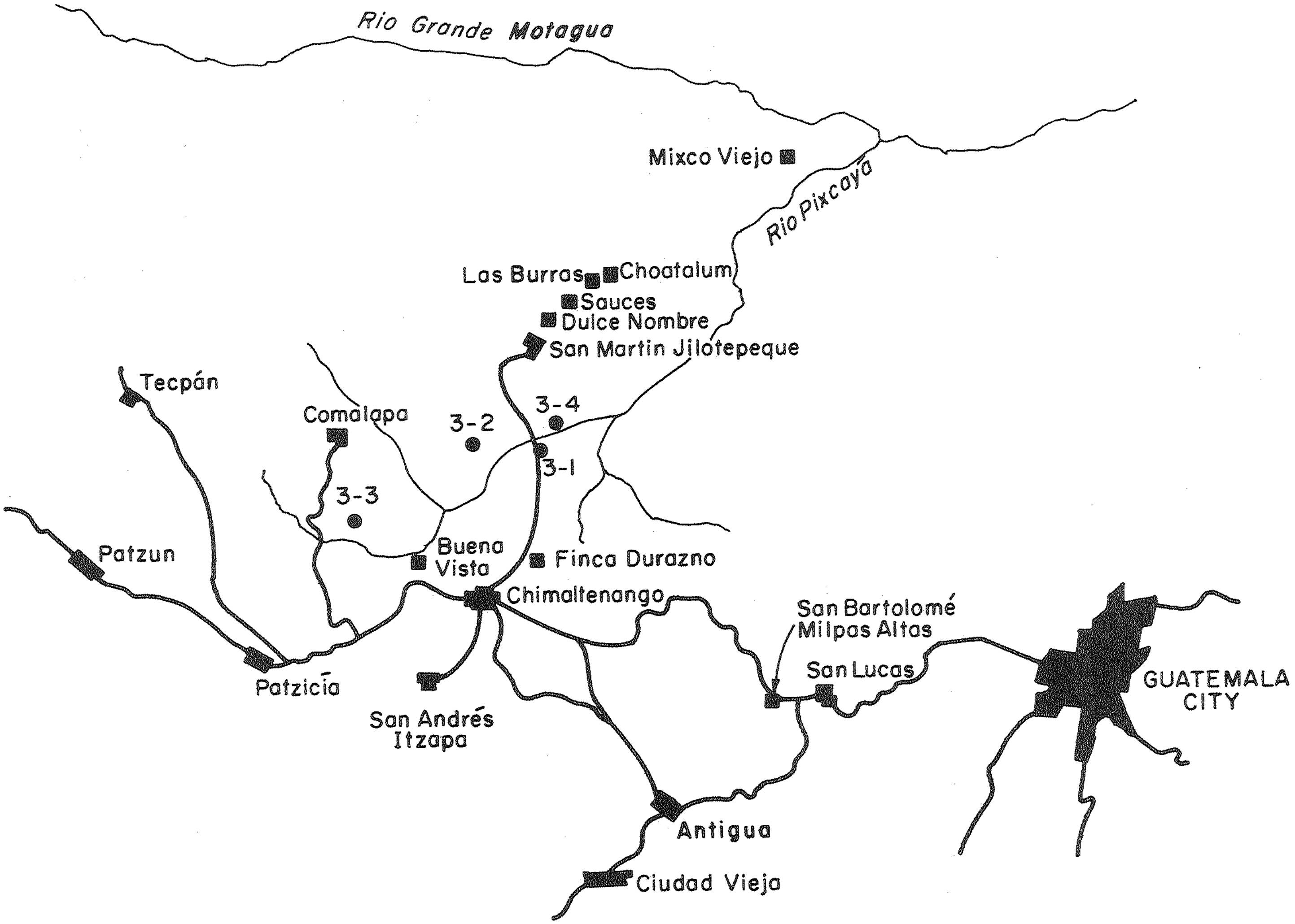

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Fig. 1 Locations of obsidian sources in Guatemala studied in this work