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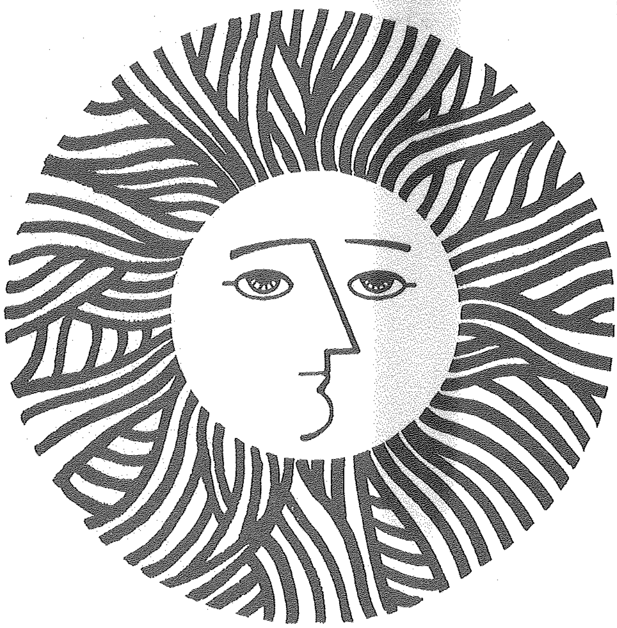

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PRECISE CHARACTERIZATION OF GUATEMALAN OBSIDIAN SOURCES, AND SOURCE DETERMINATION OF ARTIFACTS FROM QUIRIGUÁ

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ABSTRACT

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. Intercomparison of data from different laboratories 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.

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 the more important Mesoamerican source areas, specifically those in southern Guatemala.

There does not, at present, appear 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 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. A concordance of all samples analyzed in this study is shown in Appendix B.

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). The data reduction procedures are described in detail in Appendix D.

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 Cd-109 source (for Rb, Sr, and Zr) and then with Am-241 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 or 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 details and formulae are given in Appendix C. The complexity of the XRF intercalibration arises because backgrounds sometimes are not substracted for 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 Martin 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 the authors (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 homogenous 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 Sauces 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 characteristics of a geologic flow or outcrop. We may call it a "secondary" source to include the possibility, that substantial transport of 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 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 Barolomé 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) and 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 the 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. The samples analyzed by these teams appear to belong to the same composition group, which is different from any groups determined in this work.

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 Cobán, 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 these analyses are shown in Table 7 also. The composition matches neither the group of four, nor the "odd" sample analyzed 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 Copán, but it achieved independence by the mid-eighth century A.D. (Sharer 1978). The most extensive excavations to date 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.

Prior to this study, Hester (1972) described and had analyzed the macrocore that Stromsvik encountered in a lidded pottery box, packed in fine blue-colored clay, below Zoomorph G. The core is relatively small for a macrocore, measuring 16 x 12.7 x 12.0 cm, and weighing 4.9 pounds. A rapid-scan x-ray fluorescence indicated the source was Ixtepeque.

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 and 9, 24 artifacts would be assigned a provenience from Ixtepeque, and four artifacts from El Chayal. Two samples (QUIR 22 and QUIR 24) 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 (QUIR 22) agreed very closely with the average composiiton 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 10 shows the analytical results of the artifact in question (QUIR 22) and of the source samples with which it is compared. It also shows the results for the remaining unidentified sample (QUIR 24). The latter vaguely resembles the El Chayal composition pattern (average difference of 7.8% for the 16 best measured elements). 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-size 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 the authors (P.S.) has found unworked (non-artifactual) obsidian in present gravels within two 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, 75% 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 securely 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, but evidently not in alluvial deposits near Quiriguá. During the Classic Period most long-distance traded obsidian was in the form of macrocores (Hester 1972), 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 the authors (P.S.) analyzed these artifacts, and found a total of only four specimens of green obsidian. Green obsidian in the past has been found to derive from Pachuca, Hidalgo, Mexico, and therefore 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 green obsidian sources. This is very similar to Chalchuapa, where only 20 out of 40,000 obsidian artifacts were of green obsidian, or 0.05%. Tikál, 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 Chortí Maya from northern Guatemala and Belize during the fifth and sixth centuries (Thompson 1970) may have been motivated, at least in part, by a need to control access to obsidian. Teotihuacán, already in control of the Mexican obsidian trade into the Maya area, established a stronghold at Kaminaljuyú, near the large El Chayal source. The major part of the Teotihucán presence lasted from about A.D. 450 to 600 (Cheek 1977). The Teotihucán move into Kaminaljuyú 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 much of analyzed obsidian of Tikál derived from Ixtepeque (although most came from El Chayal), with little from Mexican sources, tends to support the hypothesis that the Chortí were moving southward for obsidian. Likewise the fact that so little Quiriguá obsidian evidently derived from Mexican sources, and that Ixtepeque dominates the Quiriguá sample, also tends to support the hypothesis.

These data fit Hammond's synchronic model (1972) of obsidian trade in the Maya area reasonably well. That the majority of Quiriguá obsidian would derive from Ixtepeque was predicted by the model; however, the river-transported and human-transported El Chayal obsidian was not, and the tiny fraction of Central Mexican obsidian was not as well. The Maya lowlands cannot be neatly categorized into discrete obsidian trading spheres, because Maya sites commonly were importing obsidian, in varying quantities, from multiple sources. The Olmec site of San Lorenzo is both antecedent and analogous, using multiple sources in shifting proportions through time. The explanation may be economic risk. The exploitation of multiple sources of a key commodity is less vulnerable to disruption or overcharging than relying on a single source. If, for cultural or natural reasons, a source became unavailable, greater reliance on already existing alternative supply systems is an easier adjustment than initiating exploitation of another source _a novo_. The Maya apparently spread their obsidian supply risk by diversifying sources and supply routes. Sites very close to large deposits, such as Chalchuapa and Ixtepeque (Sheets 1978), apparently felt no need to spread risk by diversification.

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FIGURE CAPTIONS

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

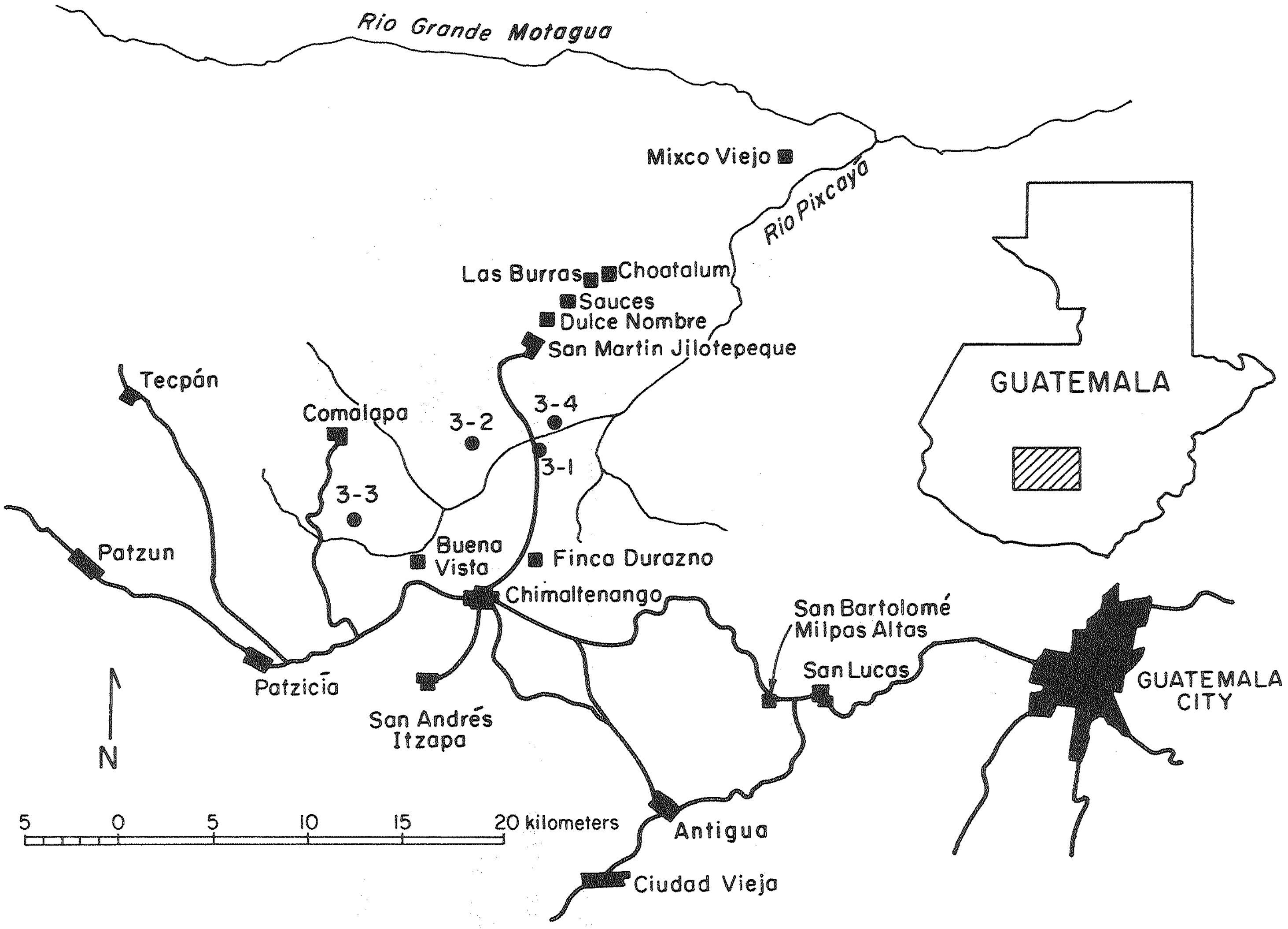

Figure 1. Locations of obsidian sources in Guatemala studied in this work

APPENDIX A

Location of Sites

Locality	Latitude N	Longitude N
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

Appendix C

Details of laboratory intercalibration procedures

In Table 1 of this Appendix are shown data by Zeitlin and Heimbuch 1978 (Z&H), Cobean et al. 1971 (CCPTK), Stross et al. 1976 (SHHJ), Hurtado de Mendoza and Jester 1978 (HM&J), Ericson and Kimberlin 1977 (E&K) and the Lawrence Berkeley Laboratory (LBL) for Mexican and well-known Guatemalan obsidians. Many of the LBL data on Mexican obsidians are unpublished (Asaro et al. 1974-1979). A sample attributed to Teuchitlán was sent by Dr. Michael Spence. Samples which were subsequently found to be correlated with the Pachuca and Otumba compositions were provided by Dr. Sisson. The El Paraiso source samples were part of the personal collection of Dr. Jonathon E. Ericson of the Peabody Museum of Harvard University.

<u>Z&H</u> - These authors made measurements by XRF on many mesoamerican source samples. The samples used and the sample preparation techniques were very similar to the early methods used by Cobean et al., (1971) but the precision of the measurements was much better. Unfortunately they did not remove the background radiation from the x-ray peaks nor the interferences of one x-ray peak with another. For example an x-ray of Sr interferes with the main x-ray of Zr and, one of Rb interferes with Y. Therefore, their measurements are not accurate and are difficult to compare directly with other working laboratories. Nevertheless, because of the carefully controlled conditions of sample preparation and measurement, the precisions of the measurements are excellent. Therefore, the data can be very usefully compared with those of other laboratories

after intercalibration.

The background for the Z&H Sr peaks was assumed to be 25 ppm. This is the value necessary to make their Sr abundance for Paraiso obsidian equal to zero. At LBL no Sr could be detected in such samples. Background for Rb and Zr would change somewhat, but within the accuracy of the intercalibration such differences are not important. Mn on the other hand would be expected to have a much larger background because lower atomic number elements are less sensitive in XRF analysis (expressed in ppm). A plot of the LBL and Z&H Mn data shown in Table 1 of this Appendix is essentially linear. On such a plot the straight line intercepts the Z&H axis at a point corresponding to a background of 53 ppm. The interference of the Sr k_β x-ray in the Zr k_α x-ray, which is the one used for the Zr measurement, is estimated (in ppm) at ~15% of the Sr abundance from the relative intensities of the x-rays. This is approximate as it also depends on the relative counting efficiency of the radiations in the Z&H experimental set up and the relative fluorescent efficiencies. The effect of the background and the Sr interference on the measurement of the standard used by Z&H (U.S.G.S. standard granite G-1), is to make the measurement of unknowns too low. The recommended abundances of Sr, Rb and Zr in G-1 are respectively 250, 220 and 210 ppm. The best Mn value, 195 ppm, is not as accurately known as those of the other elements just mentioned.

From these values the abundances of unknowns (after background and interference corrections in the unknown) should be too low by a factor of (250 + 25)/250 = 1.10; 1.11; 1.30 and 1.27 for Sr, Rb, Zr and Mn respectively. In Table 1 of this appendix the equations relating the abundance measurements of the various laboratories are given. The calibrated slopes for Sr, Rb, and Zr are within 10% of the values just given. The Mn slope, .946, is quite different from the expected 1.27 value and likely reflects some unknown error in the calibration procedure for one or the other laboratory. For example, the reference given by Zeitlin and Heimbuch for the abundance of Mn in their Standard, USGS standard rock G1, gives 0.03% for the MnO abundance which corresponds to 232 ppm Mn. A later value for Mn in this standard was 195 ppm, (a factor of 1.19 difference) and even that was not considered a recommended (good) value. The efficacy of this calibration procedure can be demonstrated by determining the provenience of a large group of obsidian sherds (unknown #1) whose origin could not be determined by Z&H although they suspected it was Zaragoza, Puebla. The Rb, Sr, Zr and Mn values given by Z&H were 162.3, 55.9 133.3 and 308.2 ppm, respectively. The recalibrated values are 139±6, 37±2, 190±6 and 239±7. These are in rather good agreement with the LBL values for Zaragoza, Puebla. of 144, ~32, ~215 and 252 respectively shown in the Table and indicate the Zaragoza, Puebla provenience is the proper one.

CCPTK - This study served as a pattern for the Z&H measurements. There is not as much detailed information on the methodology as in Z&H but apparently it was done in a similar way. For example, Sr in Altotonga obsidian is given as 30-50 ppm, but at LBL the value was 6 ppm and the revised Z&H value is 5 ppm. Therefore, the same assumptions of 25 ppm background were made for CCPTK as Z&H for Sr, Rb and Zr and also the same interference correction of Sr in Zr. Mn, however, was measured by neutron activation analysis rather than XRF. It was not evident from the paper if backgrounds were subtracted by CCPTK from the NAA peaks.

However, a plot of LBL vs. CCPTK Mn shows a linear relationship with an intercept corresponding to 115 ppm of CCPTK Mn when the LBL Mn is zero. This suggests backgrounds were not subtracted. CCPTK often gave ranges for abundances instead of individual values, and in those events the averages were used for the intercalibration. CCPTK like Z&H used USGS standard granite G-1 as a standard. It is seen from the Table that the slopes of the CCPTK calibration are within 10% of those of Z&H.

<u>SHHJ</u> - In these measurements corrections were made for backgrounds and interferences. The intercalibrations corrections are all less than 10%, but a normalization to the LBL Mn calibration was made in the data prior to publication.

<u>HM</u> & <u>J</u> - In these neutron activation measurements 48 locations were studied. It is unfortunate that abundances of different elements were not measured, but only counting rates of gamma rays at a more or less fixed time after irradiation. Although this method will discriminate adequately between sources for the laboratory making the measurements, the direct value of the measurements to other laboratories is minimal. The conditions of the experiment were sufficiently well-controlled, however, that intercalibration is practical. For this purpose those elements were selected whose radioactive products after irradiation had long half-lives and minimum interferences. Because of the uncertainties, no attempt was made to evaluate the possible errors in the calibration. To test the efficacy of the intercalibration, it was applied to obsidian measured by HM & J from Las Animas, which was supposed to represent the Ixtepeque source system. These revised abundances are also shown in the Table. They deviate on the average from

the published LBL values for the top of Ixtepeque by only 1.9%, so the intercalibration appears effective.

<u>E</u> & <u>K</u> - These authors did neutron activation analyses on Mexican sources and artifacts. Two Mexican chemical groups, Teuchitlán and Ezatlan, were measured at UCLA by E & K and by Asaro et al. at LBL, and the abundances of elements measured in common are shown in the Table. The ratios between values from the two laboratories for most elements were nearly identical for both chemical groups within the indicated errors. Exceptions were Sc and Ba. The Sc variation appears to be due to a problem one or both laboratories have in measurement of low level Sc rather than a calibration difference. So intercalibration is not feasible. The Ba discrepancies are too great to be explained by differences in calibration or variations in source abundances. The high values of Ba in these and other source samples measured by E & K must be due to a measurement error. The consistent 20% difference in Ta abundance measured by the two laboratories is commonly found between laboratories, such as LBL, which use STANDARD POTTERY as a standard and others which use USGS Standard rocks. The former is much better calibrated for Ta. The origin of the differences in Th and Eu abundances between the two laboratories is unknown, but since the differences are consistent intercalibration is feasible. Co is too low in abundance in these samples to be useful.

Table 1 (Appendix C)

Data and formulae used for laboratory intercalibration (ppm)

	Mn			Sr				Rb			Zr		
	Z&H	CCPTK	LBL^{e}	Z&H	CCPTK	SHHJ	LBL	Z&H	CCPTK	LBL^{e}	Z&H	CCPTK	LBL
Mexican sources or chemical types													
Altotonga	311.9	360-420	242^{a}	27.4	30-50		6^{a}	182.4	155-185	157^{a}			
Magdalena (Santa Teresa)	512.3	630-650	431^{a}					173.6	160-180	156^{a}			
Otumba (Teotihuacán)	475.2		391^{a}	147.5	120-150	130-150	140^{a}	149.9	120-150	130^{a}	138.5	115-160	155^{a}
Pico de Orizaba (Cerro de Minas)	646.0	~930	555^{a}					141.7	125-135		109^{a}		
Pachuca (Cerro de la Navidad)	1198.2	1275-1625	1149^{a}					217.6	175-210	211^{a}	676.7	600-870	943^{a}
Paraiso				22.3	<30		<4^{a}						
Teuchitlán	376.8	480	301^{a}					199.7	185-195	175^{a}	444.0	265-460	636^{a}
Zaragoza, Puebla			252^{a}			40	~32			144^{a}			~215
Guatemalan sources													
El Chayal	756.7		649^{b}	164.7	135-170	160-180	153^{a}	176.4	145-190	149^{b}	118.0	100-135	117^{a}
Ixtepeque	534.9		449^{b}	170.8	140-170	140-170	158^{a}	127.1	95-120	103^{b}	160.4	130-185	176^{a}

Table 1 (Appendix C) cont.

Sources types measured by NAA

	El Chayal		Ixtepeque			Teuchitlán		Etzatlan	
	HM&J[c]	LBL[a]	HM&J[c]	LBL[a]	Revised[d] HM&J	E&K	LBL[a]	E&K	LBL[a]
Ce	26.12	46.7±.9	25.39	43.3±.9	45.4	104±4	105±1	145±9	148±2
Cs	6.51	7.65±.25	2.36	2.71±.17	2.78	4.82±.11	4.46±.16	4.60±.22	4.40±.17
Fe%	2.74	.627±.027	4.01	.923±.019	.918	1.42±.04	1.34±.03	2.13±.11	2.02±.04
Rb	2.46	149±8	1.67	103±6	102	178±4	175±5	175±12	179±10
Sc[c]	13.95	1.85±.05	15.78	2.11±.05	2.09	.32±.04	.10±.02	1.13±.04	.80±.02
Th	23.11	10.4±.1	16.21	7.17±.10	7.29	18.9±.7	16.1±.2	4.64±.17	3.73±.04
Ba						2282	<50	2380	<50
Co						.08±.07	.05±.03	.09±.03	.11±.04
Eu						.14±.01	.101±.005	.19±.00	.151±.006
Ta						4.25±.11	3.41±.03	21.2±1.3	18.1±.2
Yb						6.95±.23	6.87±.09	7.24±.16	7.36±.09

Mn [LBL] = Mn[Z&H] x (.946 ±.024) - 53 = Mn [CCPTK] x (.86±.05) - 115

Sr[LBL] = Sr[Z&H] x (1.11±.04) - 25 = Sr[CCPTK] x (1.19±.03) - 25

Rb[LBL] = Rb[Z&H] x (1.01±.04) - 25 = Rb[CCPTK] x (1.10±.08) - 25

Zr[LBL] = Zr[Z&H] x (1.44±.04) - 25 - .15 x (Revised Sr) =

Zr[CCPTK] x (1.49±.19) - 25 - .15 (Revised Sr)

Ce[LBL] = Ce[E&K] x (1.013±.019) = Ce[HM&J] x (1.79)

Cs[LBL] = Cs[E&K] x (.938±.027) = Cs[HM&J] x (1.18)

Fe[LBL] = Fe[E&K] x (.946±.019) = Fe[HM&J] x (.229)

Hf[LBL] = Hf[E&K] x (.978±.013)

Rb[LBL] = Rb[E&K] x (.990±.027) = Rb[HM&J] x 61

Sc[LBL] = Sc[HM&J] x (.1326)

Ta[LBL] = Ta[E&K] x (.808±.010)

Th[LBL] = Th[E&K] x (.853±.016) = Th[HM&J] x (.45)

Yb[LBL] = Yb[E&K] x (1.006±.013)

Eu[LBL] = Eu[E&K] x (.763±.028)

a. Asaro et al. 1974-1979

b. Asaro et al. 1978

c. HM&J primary data are not element abundances but count rates at a given time after a neutron irradiation. The 889 kev gamma-ray of Sc-46 was used in the determination of the HM&J Sc values.

d. HM&J data for locality 99 (Las Animas, Department of Jutiapa) were revised with intercalibration formulae to abundances expressed in ppm or percent.

e. LBL Mn and Rb data are by NAA

Appendix D

Neutron activation analyses data reduction procedures.

The following table shows the various elements detected in each of the 5 gamma-ray spectra taken after two neutron irradiations. The first column shows the element, the second column the particular radioactive isotope used to measure that element, the third column shows the half-life of the radioactivity, and the fourth column shows the energy of the gamma-ray used for the measurement. The fifth column shows any interfering radioactive isotopes and how they are formed. In reactors with a component of fast neutrons, reactions can occur in which a proton or alpha particle is ejected after absorption of a neutron rather than the usual cascade of gamma rays. The last column shows the energy of the interfering gamma radiation. Interferences can come not only from gamma rays whose energies are tabulated in reference books, but also from interactions which these gamma rays can undergo in or near a detector. Annhilation radiation can be lost. This leaves the gamma ray energy minus 1022.0 (or sometimes 511.0) keV in the detector to interfere with measurements of the other gamma rays. There can be sharply changing intensities on the low energy side of gamma ray peaks, e.g. the Compton distribution, which make background determinations difficult and can be treated as interferences. Also, two gamma rays from a given isotope which strike the detector nearly simultaneously will cause a sum peak to appear which can cause interferences. The nuclear fission of U-235, a normal component in ordinary uranium, will produce many gamma rays some of which interfere with the measurement. Most of the interferences shown in Table are removed by computer treatment of the data, some are removed by subsequent evaluation of the data, and a very few are only removed when compositions are unusual.

Many elements are measured more than once. Comparison of the multiple values helps determine if machine errors are being made. Some of the elements which are generally not the most useful for obsidian characterization, e.g. Zn, Cr or Ni can be very useful when obsidian of unusual composition is found, e.g. peralkaline flows like Pachuca in Mexico and variable flows such as Borax Lake in California.

TABLE 1 (Appendix D)

Neutron activation isotopes and interferences

Element Measured	Radioactive Nuclide Measured	Half-life	Gamma-ray energy(keV)	Interferences which are usually removed	
				Reaction	Gamma-ray energy(keV)
11 kilowatt neutron irradiation for 10-18 min				[1.00 m gamma-ray count on unknowns, 2.00 and 4.00 m counts on STANDARD POTTERY replicates, 2.00 m on Al foil (for Mg), 8.00 m count on $CaCO_3$ pill, (for Ca) and 2.00 m count on KCl pill (for Cl)] (7 cc intrinsic Ge detector, 2-3 keV operating half-width)	
Al	Al-28	2.24 m	1778.7	Si-28 (n,p) Al-28	1778.7
*Ca	Ca-49	8.72 m	2062.4(a)		
*Cl	Cl-38	37.3 m	1642.2 2167.6		
*V	V-52	3.76 m	1434.1		
*Mg	Mg-27	9.46 m	1014.4	Al-27 (n,p) Mg-27	1014.4
*Ti	Ti-51	5.80 m	319.7		
				(6.00 m gamma-ray count on unknowns and 25.00 m on STANDARD POTTERY replicates) (7 cc intrinsic Ge detector, 1.5-2.5 keV operating half-width)	
Na	Na-24	15.02 h	1368.5 1731.9 (a)	Al-27 (n,α) Na-24 Al-27 (n,α) Na-24	1368.5 1731.9
Mn	Mn-56	2.58 h	846.8		
K	K-42	12.36 h	1524.6		
Ba	Ba-139	82.9 m	165.8	U-235 $(n,f,\beta^-,...)$(b)	165.8
Dy	Dy-165	2.33 h	94.7		
*Sr	Sr-87 m	2.80 h	388.4		
*In	In-116 m_1(c)	54.1 m	416.9		
*Cu	Cu-64	12.7 h	511.0	Na-23 (n,γ) Na-24 Br-81 (n,γ) Br-82m others (unknown)	511.0 511.0 511.0

* With the precision used in the present NAA these elements are not the most useful for obsidian characterization

(a) Double escape peak

(b) Fission correction is not normally necessary for Ba-139

(c) Calibrated via a flux monitor

TABLE 1 (Appendix D) cont.

Element Measured	Radioactive Nuclide Measured	Half-life	Gamma-ray energy(keV)	Interferences which are usually removed	
				Reaction	Gamma-ray energy(keV)
1000 kilowatt neutron irradiation for 8 hours				(starting 6 days after the end of the irradiation a 20.00 m gamma-ray each on unknowns, replicate STANDARD POTTERY for each 10 unknowns, CaCO$_3$ pill for each 20 unknowns and blank Al wrapping foil for each 20 unknowns) (1 cc intrinsic Ge detector, 600 ev operating half-width at 103 keV)	
U	Np-239	2.35 d	106.13		
Ba	Ba-131	12.0 d	123.73	Eu-153 (n,α) Eu-154	123.14(d)
Sm	Sm-153	46.8 h	103.18	U-238 (n,γ,β^-) Np-239	103.76 (PuKα_1)
				Th-232 (n,γ,β^-) Pa-233	103.86
La	La-140	40.3 h	328.74	U-235 (n,f,β^-,...) La-140	328.74
			487.00	Ba-130 (n,γ) Ba-131	486.5
				U-235 (n,f,β^-,...) La-140	486.5
*Ti	Sc-47	3.42 d	159.38	Ca-46 (n,γ,β^-) Sc-47	159.38
				Sn-116 (n,γ) Sn-117m	158.6 (e)
*Lu	Lu-177	6.71 d	208.36	U-238 (n,γ,β^-) Np-239	209.73
*Mo	Tc-99m	66.0h (Mo-99)	140.51	U-235 (n,f,β^-...) Tc-99m	140.51
*Br	Br-82	35.3 h	554.32		
*As	As-76	26.3 h	559.10		
				(starting 3 weeks after the end of the irradiation 60.00 m gamma-ray count each on unknowns, replicate STANDARD POTTERY, CaCO$_3$, and Al wrapping foil just like for previous 20 m counts) (7 cc intrinsic Ge detector, 1.9 keV operating half-width at 1.12 MeV)	
Co	Co-60	5.27 y	1332.5		
Sc	Sc-46		889.2	Fe-58 (n,γ) Fe-59	Compton distribution
				Co-59 (n,γ) Co-60	Compton distribution
			1120.5	Ta-181 (n,γ) Ta-182	1121.3
				Co-59 (n,γ) Co-60	Compton distribution
*Ag	Ag-110m(c)	252.2 d	657.7		
Ba	Ba-131	12.0 d	496.2	U-235 (n,f,β^-,...) Ru-103	497.1
Sb	Sb-124	60.2 d	1691.0		
*Cr	Cr-51	27.7 d	320.1	Fe-54 (n,α) Cr-51	320.1
				Nd-146 (n,γ) Nd-147	319.4
				Ta-181 (n,γ) Ta-182 100.10 + 222.10 =	322.20
				Lu-176 (n,γ) Lu-177 208.36 + 112.97 =	321.33

(d) Eu-154 abundance is estimated from Eu-152 abundance

(e) Sn correction is not normally necessary

TABLE 1 (Appendix D) cont.

Element Measured	Radioactive Nuclide Measured	Half-life	Gamma-ray energy(keV)	Interfences which are usually removed Reaction	Gamma-ray energy(keV)
Th	Pa-233	27.0 d	312.0	Co-59 (n,γ) Co-60	
				1332.5 - 1022.0 =	310.5
				Ir-191 (n,γ) Ir-192(f)	316.50
Eu	Eu-152	13.2 y	1408.1		
*Ni	Co-58	70.8 d	810.8		
Hf	Hf-181	42.4 d	482.0		
Cs	Cs-134	2.06 y	795.8		
			604.7	Sb-123 (n,γ) Sb-124	602.7
Rb	Rb-86	18.8 d	1007.7	Fe-58 (n,γ) Fe-59	Compton distribution
Tb	Tb-160	72.1 d	298.6	Th-232 (n,γ,β^-) Pa-233	300.1
				Ir-191 (n,γ) Ir-192	296.0
*Zn	Zn-65(c)	244.0 d	1115.5	Sc-45 (n,γ) Sc-46	1120.5
				Eu-151 (n,γ) Eu-152	1109.2
				Ta-181 (n,γ) Ta-182	1121.3
					1113.4

(Starting ∿4 or more weeks after the end of the irradiation there are 80.00 m gamma-ray counts on each unknown, the replicate STANDARD POTTERY, the $CaCO_3$ pill and the Al wrapping foil. The detector is the 1 cc intrinsic Ge and has an operating half-width of 600 eV at 145 keV.

Eu	Eu-152	13.2 y	121.78	Se-74 (n,γ) Se-75	121.09
Ce	Ce-141	32.6 d	145.44	U-235 (n,f,β^-,...) Ce-141	145.44
Hf	Hf-181	42.5 d	133.02	Ba-130 (n,γ) Ba-131	132.54
Ta	Ta-182	115.0 d	67.75		
Yb	Yb-169	32.0 d	63.12		
*Nd	Nd-147	11.0 d	91.10	U-235 (n,f,β^-,...) Nd-147	91.10

(f) Not usually a problem in obsidian

TABLE 1

ELEMENT ABUNDANCES OF CHIMALTENANGO - OBSIDIAN MEASURED BY X-RAY FLUORESCENCE [a,b]

Location:	Rio Pixcayá Riverbed	Dulce Nombre	Buena Vista	Representative Rio Pixcayá	Sauces	Las Burras	Odd Sample From Rio Pixcayá Riverbed	Aldea Chatalun		Jilotepeque	Pixcayá
								Z & H[c] (Revised)	Cobean[c] (Revised)	Z & H[c] (Revised)	Jack[d]
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±6	112±10	118±6	129
Sr	189±4	192±9	188±6	190±6	191±5	225±11	93±3	197±8	201±6	209±8	175
Zr	113±3	117±3	114±3	115±3	137±3	183±8	152±3	112±5	120±22	152±6	105
Rb/Zr	1.04±.06	.98±.07	1.02±.04	1.01±.05	.88±.06	.58±.04	.81±.04	1.13±.07	.93±.20	.78±.05	1.23
Sr/Zr	1.67±.06	1.64±.08	1.65±.06	1.65±.06	1.39	1.23±.08	.61±.02	1.76±.11	1.68±.31	1.32±.07	1.67
Mn								496±50	457± 33	594±16	515
Comment:										Like Sauces	

TABLE 2

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

					Other workers		
					Hurtado de Mendoza et.al.[c]		Jack[d]
					NAA	NAA	XRF
				Odd Sample From			
	Representative[e]			Rio Pixcayá	San Martin		
	Rio Pixcayá	Las Burras	Sauces	Riverbed	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		121	121	129
Sb	0.37±0.05	.31±.04	.46±.06				
Sc	1.99±0.03	2.013±.020	2.112±.021		2.15	2.05	
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 SACATEPEQUEZ[a]

	Finca Nimachay (this work) NAA[f]	Stross et al. - 1976 XRF	Zeitlin & Heimbuch (Revised) XRF[c]	Cobean (Revised) XRF[c]	Finca Matilandia Hurtado de Mendoza & Jester (Revised) [c] 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±.40	~20			
Mn	516±3	535	516±14	491±35	
Na(%)	3.15±.06				
Rb	139±5	115	132±6	132±11	132
Sb	.25±.04				
Sc	2.258±.023				2.30
Sm	2.525±.025				
Sr	128±4 XRF[b]	115	131±6	124±4	
Ta	.593±.006				
Th	9.77±.10	~15			10.3
U	3.22±.04				
Yb	1.649±.024				
Zr	149±4 XRF[b]	125	155±6	159±25	

TABLE 4

ELEMENT ABUNDANCES OF MEDIA CUESTA MAIN OBSIDIAN GROUP AND DEVIANT SAMPLE[a,b]

Number of Samples	1	1
	NAA	NAA[g]
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	
Sc	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[b] (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[b]					Cobean Revised[c]	Z&H Revised[c]
Rb	120±6	120±6	113±6	123±6	125±6	118±10	130±6
Sr	180±4	176±4	176±4	94±3	100±3	174±5	178±7
Zr	169±3	168±3	169±3	128±3	160±3	158±27	147±6
Rb/Zr	0.71±0.04	0.71±0.04	0.67±0.04	0.96±0.05	0.78±0.04	.75±.15	.88±.05
Sr/Zr	1.07±0.03	1.05±0.03	1.04±0.03	0.73±0.03	0.63±0.02	1.10±.19	1.21±.07
Mn						496±36	533±15

TABLE 6

ELEMENT ABUNDANCES OF JALAPA OBSIDIAN[a]

	This work NAA	Cobean (Revised)[c] XRF	Zeitlin et al. (Revised)[c] XRF	Hurtado de Mendoza et al. (Revised)[c] NAA
	1 sample			
Ba	834±29			
Ce	55.1±0.8			53
Co	0.57±0.06			
Cs	8.53±0.18			8.0
Dy	2.78±0.08[h]			
Eu	0.736±0.111			
Fe%	0.854±0.016			.85
Hf	3.39±0.06			
K%	3.70±0.26[h]			
La	27.7±0.7			
Mn	510±5[h]	461±34	525±15	
Na%	2.18±0.03[h]			
Rb	167±6	165±14	159±7	175
Sb	0.46±0.06			
Sc	3.14±0.03			3.00
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	189±5	174±7	
Zr	114±3	129±23	112±5	
Rb/Zr	1.46±0.07	1.28±.25	1.42±.09	
Sr/Zr	1.60±0.06	1.47±.26	1.55±.09	

TABLE 7

ELEMENT ABUNDANCES OF PUENTE CHETUNAL OBSIDIAN[a]

	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 Flourescence[b]		
Sr			170±6
Zr			125±5
Rb/Zr			1.27±.07
Sr/Zr			1.36±.07

TABLE 8

QUIRIGUÁ ARTIFACTS AND GUATEMALAN SOURCES COMPARED BY X-RAY FLUORESCENCE

	Quiriguá samples	El Chayal source	Quiriguá samples	Ixtequeque 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 9

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 10

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)

a. 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.

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

c. See Appendix C for intercalibration procedures and formulae.

d. 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.

e. 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.

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

g. Measurements were made by an abbreviated NAA sequence.

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