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The Maya who inhabited much of southern Mexico, Guatemala, Belize, and Honduras during their Classic Period, (approximately 600 - 900 A.D.) left a rich legacy of cultural achievement. They excelled in monumental architecture, calendrics, writing, and a varied array of sculptural and decorative art forms. Included among the latter are painted ceramic vases on which the Maya artisans could portray historical events as well as illustrate their view of man's relationship to natural and supernatural forces. It is no surprise, therefore, that the study of Maya pottery and its representational art is a dominant focus of attention for the archaeologist and art historian as both attempt to understand the organizational principles and functioning of Maya society.

Although they were previously encountered mainly in Natural History museums, the pictorial ceramic vessels created by the Maya are today found increasingly within the collections of Fine Arts museums. Their aesthetic appeal to the modern viewer as well as the appreciation of their iconographic messages has been greatly enhanced by the scholarly, well-illustrated books of Coe [1,2,3] and others [4]. Several scholars have suggested that the vessels may have been funerary in function, being placed with the dead as part of the grave paraphernalia. This interpretation is strengthened by the iconographic content: many of the major themes deal with death and apotheosis, or with gods and heros; on the other hand, some do portray scenes or bear hieroglyphic texts concerning historical individuals and events. All in all, Maya pictorial pottery may be viewed both from a perspective of aesthetic appreciation or as an invaluable source of information about the natural or cosmological world of the Maya.

Lamentably, few of the vessels have been found by scientific excavation. The resultant lack of spacial (as well as contextual) control dramatically reduces the potential information to be gleaned from a study of the pottery. For this reason, the Research Laboratory of the Museum of Fine Arts, Boston and the Department of Chemistry at Brookhaven National Laboratory have undertaken an intensive program of trace element analysis, seeking to characterize the ceramic paste and, hence infer a delimited source for a vessel's origin. If a probable area of raw material procurement may be established, individuals, themes, or hieroglyphic texts found on the pottery may be placed into spacial perspective. In the absence of a probable source for the pottery, the paste compositional data still provides an empirical means of assessing vessel to vessel similarity, thereby yielding information concerning the relationships among different "styles" or "schools" of Maya ceramic art.

We have now completed five years of analytical effort along these lines and have established a paste compositional data bank for Maya pottery which contains over 12,000 trace element analyses, including those of approximately 1,500 whole vessels. The massive accumulation of analytical data has required that increasingly more sophisticated and efficient methods be developed for transforming the data to render it archaeologically more readily interpretable. Both the conceptual and practical aspects of data manipulation have commanded our attention. Since our scope in this paper is limited, we will do little more than illustrate how the Maya ceramic data bank can be used to assign a probable source of origin to non-provenienced, epigraphically and iconographically important vessels. While aspects of form and decoration will shortly be encoded in our data bank, our present comments deal primarily with the interpretation of the chemical data as it is seen to covary with selected styles of Maya painting. These covarying attributes, style and paste composition will form the basis for a hierarchy of vessel attribution which is decreasingly specific: site specific; sub-regional; and hypothetical. Taken together, these levels of attribution will illustrate how the trace-element data can merge archaeology and art history and address questions concerning Maya art and society.

Chemical data for the project was derived by instrumentational neutron activation analysis, following routine analytical procedures described in detail elsewhere [5]. Our method of sampling whole vessels was guided by an effort to minimize the size of the burred area (usually on the base, away from view) while achieving analytical reproduceability. Actual sample size varied from 50 to 200 mg, depending on vessel thickness. Analysis carried out on the smaller samples frequently showed non-reproduceable manganese concentrations, and since that element is one of three that we routinely obtain from a short irradiation, we have relied on only those fifteen elements whose concentrations may be determined during a single gamma count eight to ten days following a long bombardment. A single count also expedited the production of a large number of analyses--a requisite for the compositional characterization of the vast geographical area of investigation, and the very large number of whole vessel samples. Since we have retained our previously-analyzed samples, short irradiations could still be performed in the future if needed to resolve particular questions.

We should emphasize that we are not necessarily attempting to relate the pottery directly to the clays or other raw materials employed in its maufacture, although this approach has been successful in other investigations [6]. The multi-component nature of Maya ceramic fabrics, with their varied mineralogy, grain size distributions, and manufacturing histories, forces us to a higher order of abstraction; we are compositionally analyzing the choices and products of cultural activity rather than naturally occurring materials [7]. As an example, although the clay from a given source may be more or less homogeneous in elemental concentration, the addition of components such as volcanic ash, crushed carbonate rock, sand, or other clays may significantly alter the compositional profile of the original clay. For this reason, greater reliance in the task of relating compositional characterization to locality of origin is placed on the "criterion of abundance"[8]. Briefly stated, this rule holds that the type of pottery that is strongly represented or that has extended continuity through time at a site is more likely to be of local origin and thus can be used to establish a representative profile for locally produced pottery. Although there are weaknesses in this approach, it nonetheless provides a point of departure in compositional investigations, and is usually acceptable to the archaeological community.

The most important factor in the successful characterization of a site's or region's locally produced pottery is the intensity of sampling; given the paucity of detailed excavations or even surface collections, our sampling is obviously incomplete, but it does represent a beginning. The principal Maya sites which have been the focus of more extensive ceramic sampling are shown in Figure 1. From each of those sites indicated, 75 - 150 polychrome sherds produced between 300 - 900 A.D. were analyzed. The pottery from approximately another fifty sites has also been sampled but to a lesser degree. Outside of the heartland of Classic Maya polychrome production but serving to provide compositional perspective, over 2000 analyses of pottery have been carried out, focussing on the site of Palenque and outlying sites in northeastern Chiapas and adjacent Tabasco. Our coverage is certainly uneven and yet distinct compositional trends across the Maya area are being observed and "key" elemental concentrations are being noted. For example, pottery produced from clays in the Usumacinta and Motagua river drainages are notable for their high chromium values: they exceed 1,000 parts per million--a factor of ten or more greater than the usual levels in Maya pottery.

Even with intensive sampling, the number of analyzed samples that may constitute a "homogeneous" group may not be large. It is not infrequently the case that multiple reference groups or representative compositional profiles need to be formed in order to represent more realistically the local ceramic production at a site; clay beds may be exhausted or access to them restricted, different tempering materials may be utilized, and changes can occur in the production stages. The need for multiple reference units combined with the elimination of the "non-local" or intrusive samples reduces the number of analyses that will constitute a reference group. These smaller units, if archaeologically as well as chemically reasonable, may well be adequate for purposes of attributing non-provenienced vessels. If they are too small to be considered "representative" they might be susceptible to merging with other geographically close groups to create a larger "synthetic" reference unit for sub-regional characterization [9].

Stated differently, we seek to utilize the analytical and archaeological data in an attempt to subdivide the Maya area into the smallest divisable units which are maximally similar within themselves and demonstrably separable from other such units. The realities of incomplete coverage and selective sampling necessitate varying operational as well as conceptual levels of data synthesis. The successful manipulation of the trace element data is confirmed in part by the degree of stylistic similarity within our compositionally derived groups. It is these units, at the site specific or sub-regional level which provide the basis for the attribution of the non-provenienced vessels.

This concept of site specific compositional characterization may be illustrated by the results on the pottery from the site of Tikal, Guatemala. Here, a single compositional unit has been obtained which is comprised of non-carbonate tempered pottery representing several different ceramic periods of that site but which, because of our inevitable bias toward analyzing what is available and representative, leans heavily on the analytical composition of the Late Classic figure "dancer" plates (Figure 2a) [10]. As stated above, for this to be a useful reference unit, it must be relatively homogeneous and statistically differentiable from the locally produced pottery at other sites in the vicinity. As may be observed in Table 1 although some elemental concentrations are similar to those of pottery from the site of El Sotz, approximately 35 km distant, some concentration levels, particularly those of the rare earths and hafnium, serve to differentiate the compositional profiles of the two sites.

Given that one or more compositionally homogeneous and archaeologically meaningful groups can be formed to represent the pottery locally produced in or about a site, statistical procedures employed in the evaluation of the group can be extended to non-group samples such as non-provenienced vessels. (Many of the statistical approaches are discussed elsewhere [5].) One of the more powerful approaches is to calculate the variance-covariance properties and centroid for a group of specimens as well as the Mahalanobis distance of each sample from that centroid. From the distance, probabilities that individual samples could belong to the group are calculated. These calculations cannot only adjust for a varying number of samples comprising the reference group, but also take into consideration the pattern of interelemental correlation as well as the sample's proximity to the group centroid [11].

As noted above, a Tikal reference group was formed which, although stylistically biased toward the figure plates, still contained other sherd material also found at Tikal, and of presumed local origin. To this group the chemical profiles of the whole corpus of non-provenienced vessels were one by one multivariately compared revealing several additional specimens which were observed to have high probabilities of belonging to the Tikal group. Included among the newcomers were several in the figure plate style (e.g., Figure 2b). These data strongly suggest that ceramic specialists at or around Tikal were engaged in the production of these distinctive plates. If our assumptions and statistical procedures are valid, then a probable source of manufacture for the unprovenienced museum specimens has been ascertained. The bringing together via compositional data of a number of these figure plates also provides a sound, empirically derived group of stylistically related vessels with which the art historian can now investigate aspects of stylistic variation within a restricted geographic area of production, and be relatively sure he or she is not dealing with widely-separated production centers.

In the absence of a site specific characterization, it is necessary to resort to a sub-regional perspective: an expanded compositional unit formed by a merger of groups or reflecting a particular pattern. Although some specificity of manufacturing location is lost, the compositional data provide an objective basis for a vessel to vessel comparison. For example, members of a stylistically related group of vessels can serve, each in turn, as a reference point from which to assess the extent of similarity of it to every other sample in the data bank. Since a compositional group with its set of elemental variance covariance relationships is not known, similarity can be based on simple Euclidean distances (or other measures of association). A computer program for chemical profile matching within the data bank has been developed, but not all "close" matches are of equal utility. For example, if a reference sample lies near the center of its actual (or natural) group, then samples close to it will most likely be other members of that group. However, if the reference point is tending toward the periphery of the group's distribution, non-group members may be as close or closer to the reference point than other members of the group to which the reference sample belongs. One application of this type of data searching has been to vessels which we refer to as the Area Group: examples of which are shown in Figure 2c,d [12].

Conducted as a test of the data bank searching techniques, stylistically similar vessels were selected, using five by seven photographs, from the whole vessel corpus. The group is defined by such shared attributes as a similar palette: red-orange, gray and black slip painted on a cream background, while the two-dimensional picture plane is filled with iconographic forms and decorative details, as well as red rim bands with black painted glyphs. The painting technique employed quick brush strokes which produced loose black outlines and overlapping fill-in colors. The iconographic program is as consistant as the artistic style for these vessels portray either anthropomorphic or zoomorphic versions of the Underworld Paddlers, or depict God N, one of the chief Underworld gods [12].

When each of these vessels was used in turn as a reference point some--but not all--of the stylistically similar vessels were found to fall within a set level of "acceptable" chemical similarity. One vessel, which must have been occupying a more central position in the sample distribution revealed close similarity to most of the other vessels and to excavated sherds from two sites which showed iconographic elements resembling those on the Area Group specimens. Once a pattern of overlapping compositional simmilarity was observed, the related profiles could be brought together to form a group and thus evaluated by the same multivariate statistical procedures employed in the Tikal example. These procedures resulted in a group of twenty-seven specimens of which nine were of the Area Group style. Elemental mean concentrations and percent deviation values are given in Table 1.

If the probability distribution about the twenty-seven samples is enlarged to include those specimens lying just outside of a 95% confidence interval, we begin to include many with a Tikal provenience. One can note the similarity between the mean elemental concentrations of the Area Group vessels and those of the Tikal reference unit in Table 1. Although we cannot say that the specimens of the Area Group were made at Tikal, we can infer a manufacturing location somewhere in the general Tikal-Uaxactun sub-region as opposed to other characterized sites or sub-regions in the Maya Area.

There were three vessels that had been tentatively placed within the pictorially sorted Area Group, on the basis of their styles. However, each was divergent in one or more pictorial or iconographic attributes which brought into question its group membership. Indeed, each was afterward found to have a chemical profile which was divergent from the others in the Area Group, suggesting that they were formed from different clays and painted by artists other than those responsible for the Area Group specimens. Such data are of critical importance for investigations of Maya ceramic art and the nature of craft specialization. Additionally, these data attest to the strength of compositional and stylistic covariation in Maya elite pottery.

Another group of ceramic vessels which illustrate chemical as well as stylistic homogeneity are those painted in a "codex style", characterized by the use of a fine black, black-brown whiplash line on a cream slip with red bands at the rim and base. A little more than a decade ago few of these vessels were known; they now number more than two hundred and have been the subject of a recent book which hypothesized that the scenes on the vessels could be sequenced to illustrate an Underworld tale or myth [4]. A previous compositional investigation of approximately thirty samples of codex style pottery suggested a single producion area somewhere to the north of the Tikal-Uaxactun-El Sotz area [13]. The general location of the production area was inferred from an observed similarity of the codex pottery to non-codex pottery from El Sotz and Uaxactun and slightly less resemblence to Tikal ceramics. In other words, viewing the Maya area as a whole, it was possible to eliminate large geographical areas by reference to compositional trends. Subsequent analysis combined with recent excavation has revealed chemically matching codex pottery from the sites of El Sotz and El Mirador in northern Guatemala--well within the sub-region previously suggested. As with the Area Group, the analytical data for the codex style vessels are consisent with a view of stylistic and compositional cohesiveness and sub-regional localization of production.

Not unexpectedly, we often encounter vessels apparently produced from raw materials for which a compositional reference group is at present lacking. In some instances the presence of a glyphic text may suggest a source for the vessel. The compositional and epigraphic analysis of Maya cylinder MS0651 illustrates what we refer to as the hypothetical level of vessel attribution. The text on MS0651 seen here in a rollout photograph by Justin Kerr (Figure 4) begins with the date 3 Ben 6 Kankin. This corresponds to the Maya Long Count position 9.12.11.9.12, or November 11, 683 A.D. (GMT correlation). The passage records a bloodletting ritual performed by the lord seated on the throne. His personal name is a glyph read as AH GOD K. This follows the nominal tradition of Petexbatun rulers, which includes such individuals as FLINT SKY GOD K, SHIELD GOD K, and SCROLLHEAD GOD K. Further, AH GOD K's nominal phrase ends with the Petexbatun emblem glyph; this emblem glyph, also found on monuments from this region, is either the name of a particular royal lineage or denotes the site itself.

The Petexbatun region of the Guatemalan southern Peten Lowlands is archaeologically poorly known with no scientifically excavated ceramic information. However, the region has many carved stone monuments whose glyphic texts yield a rich trove of historical and political information. Although it is not possible to directly connect AH GOD K with any of the individuals found on the monuments, the similarity in the pattern of the glyphs and the presence of the emblem glyph relate him to the ruling line [14].

The glyphic text, then, suggests a hypothetical area of manufacture for vessel MS0651. Yet, the vessel could conceivably have been made in some other area and served only to comemmorate an event which took place in the Petexbatun. When the chemical data for the vessel is used as a reference point for searching the data bank, only a very few non-provenienced vessels were found to lie within the Euclidean distance limits usually employed when working with pottery from other sections of the Maya area. This could imply either the vessel was manufactured in a region from which we have not sampled the pottery or that the vessel was made from a different clay from the regions where we do have sampling coverage. When we increase the measure of Euclidean distance, lessening our criterion of similarity, we begin to extract from the data bank samples from the site of Seibal, Guatemala--the closest site to the Petexbatun from which we have analyzed pottery. While far from conclusive proof, the fact that MS0651's closest similarity with provenienced pottery occurs with that from Seibal supports the notion that MS0651 could have been made in the Petexbatun. As more vessels are analyzed, MS0651 can serve as a reference point representing pottery with a hypothetical origin in the region.

We have discussed the procedures and a few of the results of the Maya ceramic project from the perspective of non-provenienced vessel attribution ranging from site specific through a more inferential level to the rather hypothetical. The few examples presented at least serve to illustrate the manner in which we are attempting to view compositional and stylistic covariation in an investigation of Maya Ceramic art. The large data base including archaeologically recovered pottery as well as the stylistically and iconographically elaborate vessels requires continued refinement in our methods of statistical analysis along with gaining a greater understanding of the sources of ceramic compositional variation in the Maya area. Above all, it emphasizes the mutually beneficial collaboration between science, art, and archaeology.

Acknowledgments

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Figure Captions

Fig. 1. Map of Maya area indicating sites of intensive ceramic sampling.

Fig. 2. a. Figure painted polychrome plate excavated at Tikal, Guatemala.

b. Non-provenienced figure painted plate with compositionally based probability of having been made in Tikal area.

c&d. Examples of Area Group style of painted vessels.

Fig. 3. a,b,c. Examples of codex-style painted ceramics.

Fig. 4. Rollout photographic of vessel MS0651; photograph copyrighted by Justin Kerr.

Table 1. Comparison of Mean Concentrations and Percent Deviations in Ceramic Reference Groups.

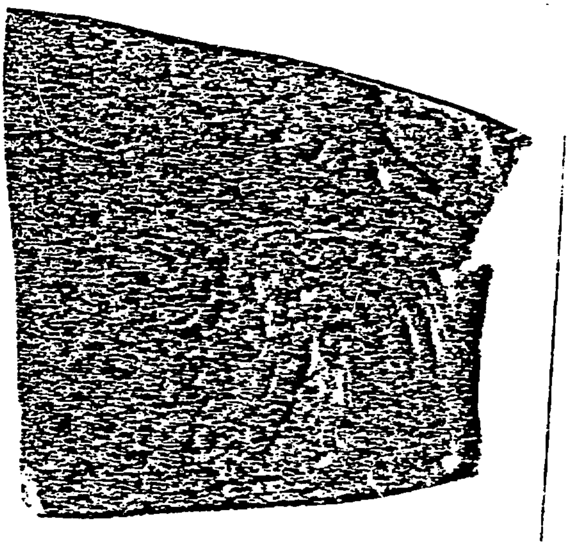
Element Analyzed	Area Stylistic Group N = 9	Tikal Reference Group N = 30	El Sotz Group* N = 28
Rb_2O	79.0 (33)	84.0 (25)	117.0 (22)
Cs_2O	2.5 (20)	3.4 (28)	4.4 (29)
BaO	.18 (28)	.12 (39)	.13 (50)
Sc_2O_3	14.0 (7)	20.3 (13)	16.0 (16)
La_2O_3	16.5 (6)	19.3 (18)	32.2 (24)
CeO_2	33.0 (13)	41.0 (18)	74.0 (25)
Eu_2O_3	.35 (9)	.65 (22)	.93 (34)
Lu_2O_3	.27 (13)	.37 (20)	.56 (16)
HfO_2	5.3 (10)	6.8 (12)	9.0 (30)
ThO_2	15.3 (6)	15.8 (11)	20.0 (20)
Cr_2O_3	46.0 (7)	73.0 (35)	91.0 (34)
Fe_2O_3**	3.3 (8)	4.7 (12)	3.1 (18)
CoO	6.3 (30)	6.7 (17)	8.9 (31)
Sm_2O_3	2.1 (11)	3.0 (27)	4.8 (24)
Yb_2O_3	1.4 (19)	1.9 (27)	3.2 (17)

* It is quite likely that the El Sotz group will undergo further refinement as work progresses. The Tikal reference group represents the more frequently encountered deviation ranges when working with Maya volcanic-ash tempered pottery. Parentheses contain standard deviation expressed as %.

** Fe_2O_3 concentration in %, all other in parts per million.


BECAN
HOLMUL
YALOCH
LAMANAI
ALTUN HA
UAXACTUN
EL ZOTZ
TIKAL
SAN JOSE
BARTON RAMIE
NAKUM
FLORES
PIEDRAS NEGRAS
ALTAR DE SACRIFICIOS
SIEBAL
LUBAANTUN
POPTUN
CHAMA
NEBAJ
CHIPOC
SAN JERONIMO
QUIRIGUA
ACASAGUASTLAN
COPAN
Seibal

Figure I



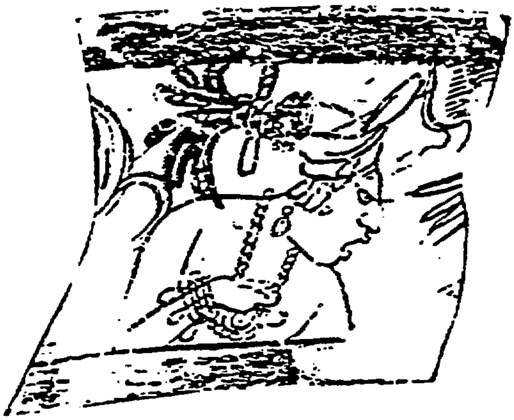
a

b

c

d

Figure 2



a

b

c

Figure 3

Figure 4