DEAN E. ARNOLD
Wheaton College, Illinois

HECTOR NEFF
University of Missouri

RONALD L. BISHOP
Smithsonian Institution

Compositional Analysis and "Sources" of Pottery: An Ethnoarcheological Approach

One of the important assumptions of compositional analysis is that the elemental composition of an artifact reflects the source of the materials used to make it. Thus, pottery from a particular source will be chemically similar to the raw materials from that source. This "commonsense" assumption seems beyond dispute, but the fact that pottery is a mixture of clay, water, and often temper added by the potter, complicates the interpretation of compositional data from ceramics. This article examines the relationship between potters' behavior in obtaining and using raw materials, on the one hand, and the chemical composition of their finished pottery, on the other, by comparing the elemental composition of ethnographic pottery and raw materials from contemporary pottery-making communities in the Valley of Guatemala. The results of this research show that the relationship between pottery and its constituent raw materials is not as obvious as was first supposed. The article concludes with an alternative approach to compositional analysis that is more in line with the realities of real-world pottery production.

FEW ANALYTICAL APPROACHES HIGHLIGHT the problems of relating human behavior to its material residues more than the compositional analysis of pottery. For archeologists, the problem of compositional analysis consists of relating the chemical composition of an artifact to the behavior of its producer. Unfortunately, the elemental composition of pottery (like that obtained from instrumental neutron activation analysis, inductively coupled plasma spectroscopy, or atomic absorption spectroscopy) is difficult to relate to potters' behavior because the relationship between the chemical elements in the pottery and the potters' behavior is not obvious.

In order to relate the chemical elements in the pottery and potters' behavior, archeologists and "archeometrists" assume that the ceramic composition reflects the composition of the source raw materials (usually clay). This "commonsense" assumption works well with some natural materials unaltered by humans (e.g., obsidian), but the complex chemical and behavioral factors involved in pottery production can affect the simple relationship between the chemical elements in the pottery and the supposed source of its constituent raw materials. With ceramics, the concept of "source" is thus problematic because "source" can be thought of as a single mine, a single widespread clay stratum, all clays in a single drainage, a single community of potters, or perhaps even a group of such communities. One way to evaluate the assumption relating the elemental composition of pottery and behavior is to analyze materials from living communities of potters

DEAN E. ARNOLD is Professor, Department of Sociology/Anthropology, Wheaton College, Wheaton, IL 60187. HECTOR NEFF is Research Scientist, Research Reactor Facility, University of Missouri, Columbia, MO 65211. RONALD L. BISHOP is Resident Archaeologist, Conservation Analytical Laboratory, Museum Support Center, Smithsonian Institution.

in order to discover how the elemental composition of pottery relates to procurement and preparation patterns.

Setting aside for a moment the problems with the concept of "source," there are a number of other problems complicating the relationship of the elemental composition of pottery to human behavior. First, potters neither perceive nor select the chemical elements in their raw materials, but rather may identify and select their materials on the basis of obvious physical properties like color (Arnold 1971:28; Arnold 1978a:364, 367), plasticity (Arnold 1971:31), the amount of nonplastics present (Arnold 1972:97), the presence or absence of "goldlike" particles (Arnold 1972:97), drying characteristics (Arnold 1971:30), or a salty taste (Arnold 1971:29–30). These physical properties are not clearly or unambiguously expressed in the chemical elements of the ceramic paste.

In addition to the potter's lack of perception of the chemical elements in the selection of raw materials, paste composition may be affected by other behavioral factors. Any substance that the potter mixes with clay may cause the trace element composition of the pottery to diverge from the composition of the "source" clay. Water, for instance, is a necessary ingredient for all ceramics. But, water contains soluble salts of such elements as sodium, potassium, magnesium, calcium, and iron, and the concentrations of these elements may thus become enriched when water is added to clay to achieve plasticity. Besides water, the potter may mix temper with the clay to change its working properties. Although this "temper" is usually believed to consist purely of nonplastics, it may consist of a mixture of plastic and nonplastic materials (as it is in Ticul, Yucatan, Mexico [Arnold 1971] and Quinua, Peru [Arnold 1972]). Compositional analysis of ancient pottery thus not only reveals the composition of the raw clays used to make it, but also that of the other components (like water and temper) added by the potter. Other factors that have been suspected to cause the compositional profile of pottery to diverge from the chemical profile of the source clay include: levigation (e.g., Shepard 1956:52, 182; Rye 1981:17; Rice 1987:119; Kilikoglou, Maniatis, and Grimanis 1988; Hart et al. 1987:590); firing (Perlman and Asaro 1969); use (Vitelli, Tankersley, and Shaffer 1987); and post-discard processes (Vitelli, Tankersley, and Shaffer 1987; Franklin and Vitali 1985).

While it is not possible to deal with every variable affecting the composition of fired pottery, it is possible to investigate how closely the elemental composition of fired pottery reflects its source materials in an ethnographic context with known behavioral variables (see Arnold et al. 1978; Rice 1978b). How closely does the elemental composition of pottery from a community reflect the composition of its constituent clay? How does temper affect the elemental composition of the fired pottery? Answering these questions by analyzing ethnographic pottery of known provenience will help sharpen the methodological and conceptual tools of the elemental analysis of pottery and permit more precise inferences about trade, exchange, and production when this analysis is applied to ancient pottery.

The Ethnographic Background

To examine the effect of cultural factors on the chemical composition of pottery, 273 samples of pottery, clay, temper, and paints were collected from pottery-making communities in the Valley of Guatemala during the summer of 1970. Of these, 153 samples were analyzed by instrumental neutron activation analysis (INAA) to examine the chemical expression of such cultural factors as choice of clay source, tempering, and lack of tempering on trace element composition of pottery, and to determine the extent of elemental variability among sources and communities. The goal of the research was to understand what procurement variables (like clay source and temper source) affect the trace element composition in modern pottery and thus to test the assumptions linking the elemental analysis of pottery (obtained from neutron activation analysis) and potters' procurement behavior. By controlling the variables of space and time, one can discover the compositional variability that results from source locations and temper contamination and the variability that does not result from these factors.

Most of the samples were obtained from three communities, Chinautla, Sacojito, and Durazno, but some were also collected from the nearby communities of Mixco, Sacoj, and La Cienaga (Figure 1). With a few exceptions, these samples were "cultural" samples. That is, they were samples of clay, temper, and pottery collected from potters' households. A few samples were collected at the raw material sources, but most were collected from their geological source by local potters using their own selection criteria. Relying on potters for selecting raw materials minimized the chance of a collecting bias based on ethnocentric or geological criteria that have little to do with the potters' behavior. Trace element variability could thus be related more clearly to potters' behavior, rather than to culturally extraneous criteria.[1]

The communities of Chinautla, Sacojito, and Durazno all speak the same dialect of Pokomam (sometimes called central Pokomam) and were part of the Pokom state in the 16th century. They all belong to the *municipio* of Chinautla, and thus some interaction occurs among the three communities.

These communities share the same pottery-making tradition, with only minor differences between them. This tradition consists of a set of cognitive and behavioral rules (both conscious and unconscious) about resource selection, mixing, and vessel fabrication that appears to have a common origin in the past. The products of this tradition consist predominantly of: (1) a tempered whiteware, which potters (who are women) use to produce four major vessel shapes (see Arnold 1978a) and (2) a tempered redware, which potters use to produce water storage jars and cooking pots. Chinautla potters also use the redware clay to produce toy miniatures and incense burners, and may sometimes use it to produce the same vessels produced with the whiteware paste. Sacojito potters make few redware vessels. Although samples of pottery and raw materials were collected from all wares, most samples consisted of whitewares and their constituent raw materials.

Chinautla and Sacojito potters produce whiteware by using white clay, whereas Durazno potters use a black carbonaceous clay and a white slip to produce their whiteware vessels (see Arnold 1978a; 1985). Chinautla (and some Sacojito) potters sometimes also add a white slip to produce the ware.

All of the raw materials for these wares come from a distinct set of sources. The white clay used in Chinautla and Sacojito consists mostly of the clay mineral kaolinite with some quartz present. It comes from a single mine 1.5 km north of Chinautla and 1.5 km northeast of Sacojito (see Figure 1 and Arnold 1978a, 1978b, 1985:173) near the Finca La Primavera. The white-firing clay from Durazno comes from several clay pits in an area roughly 10 meters by 50 meters located in Durazno (see Figure 1 and Arnold 1978a, 1985:173).

The potters temper their pottery with volcanic ash. Each community has several temper sources: Durazno has at least two sources, Chinautla has at least three, and Sacojito has two (see Figure 1 and Arnold 1978a:332, 368, 372, 381–382; 1978b:47; 1985:173). Potters in Chinautla and Durazno reported more sources "in the forest" or "hills," but all temper sources visited or identified lie within 1.5 km of these communities and all are within the quaternary volcanic ash deposits that blanket the northern Valley of Guatemala.

There are a variety of sources in or near each community for the clay used in making the redwares. This clay is usually yellow (and occasionally brown) in its raw state, but fires to an orange, red, or brown color. Some redware clays contain enough nonplastics for making pottery (e.g., Mixco, Sacoj, and La Cienaga), while others require added temper (e.g., Chinautla and Sacojito). Some Durazno redware clays require temper, while others do not. Potters in Chinautla obtain red-firing clays from the banks of the river that flows through the community, while Durazno potters obtain these clays from a variety of locations. Frequently, each Durazno potter has her own private source for this clay in or near her household, but some sources are located 4–5 kilometers north of the community along the road to the town of Nacahuil. Sacojito potters reported two sources for redware

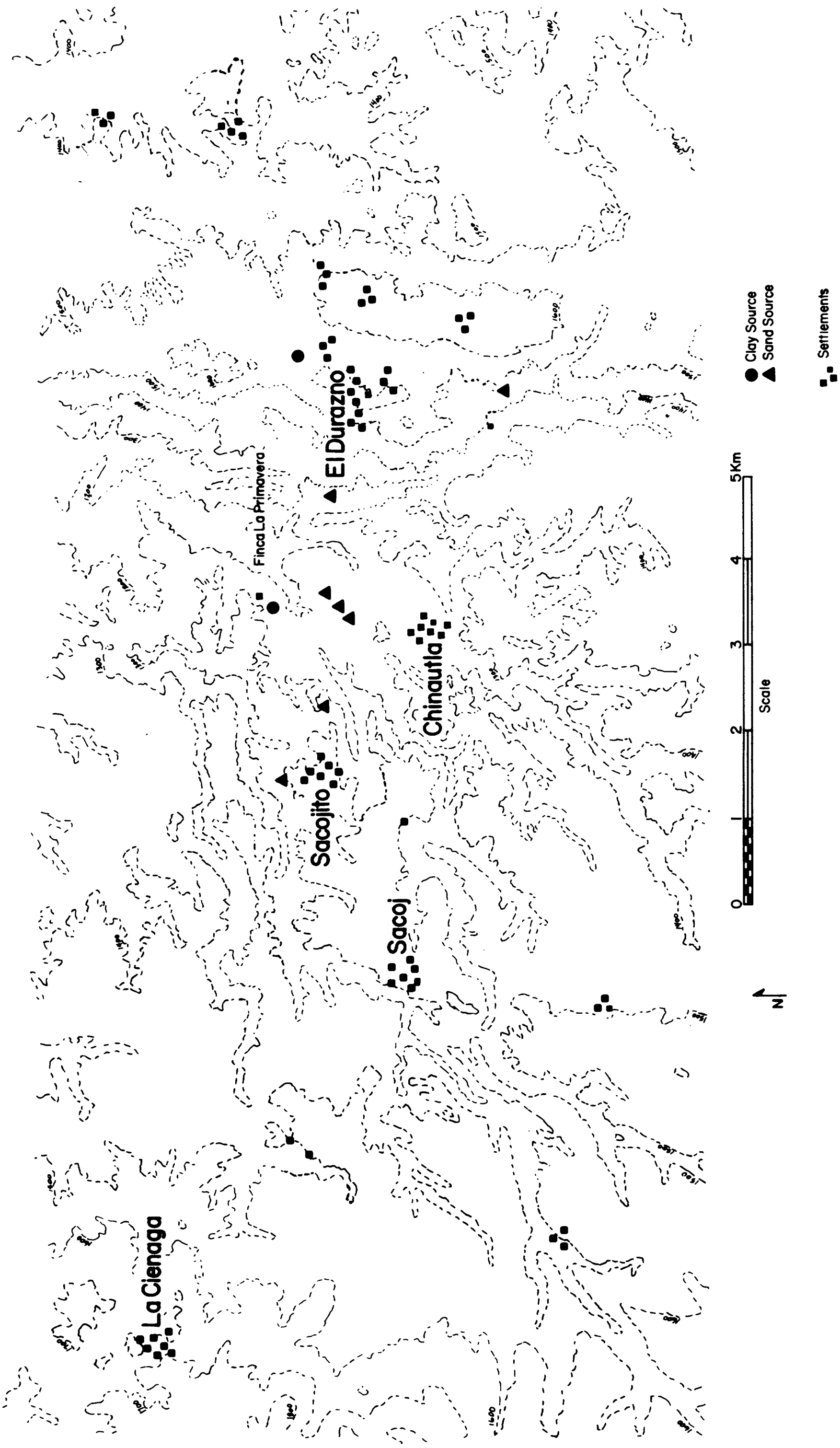

Figure 1

Topographic map showing the pottery-making communities and sources of whiteware clays and tempers in the northern Valley of Guatemala. Contour intervals are 100 meters. Mixco is not shown on this map, but is located 15 kilometers southwest of Chinautla. Sources of redware are not shown. (From Arnold 1985:173.)

clay: one in the gorge west of the community and the other in the gorge south of the school (see Figure 1).

In the communities of Sacoj and Mixco, potters utilize an untempered paste to make their redwares. Mixco potters make exclusively tortilla griddles *(comales)*, whereas Sacoj potters make exclusively cooking pots (except for potters originally from Chinautla). In these communities, each potter has her own particular location where she obtains clay. In Mixco, clay may be mined from a hole in the yard, but at least one potter traveled a kilometer to obtain it. In Sacoj, makers of cooking pots said they obtained their red clay from the gorge north of the community. Two other women have moved to Sacoj from Chinautla and make Chinautla-style pottery, but they still use the white clay from the Chinautla/Sacojito mine for most of their vessels.

La Cienaga represents the only non-Pokomam-speaking community visited. Potters there speak Cakchiquel and produce only tortilla griddles *(comales)* with a redware paste, but they use a different forming technique than the Mixco potters (Arnold 1978b:331; Reina and Hill 1978:44–50). Like the potters of Mixco, each of the La Cienaga potters obtains her clay from a different source, which may occur within her houselot.

Previous Work

The instrumental neutron activation analysis of these specimens have been reported (Arnold et al. 1978), but the methods employed in these studies were biased because of low analytical precision and internal inconsistencies. The precision of a neutron activation analysis is highly dependent upon the number of gamma counts recorded for a given radioisotope. The smaller the number of counts, the larger will be the statistical error associated with quantifying the isotopic abundance. A small number of counts also makes it very difficult to separate gamma peaks from others close to it or from general background noise. Given the specific sampling, irradiation, and counting configuration (involving short counting times of 400 seconds) in the earlier study, one would expect very small total gamma counts, and, consequently, large statistical errors in the results. The data were also expressed as ratios to scandium rather than normalizing the counts to a standard material. This practice further introduced additional errors and limitations on internal consistency (Neff, Bishop, and Arnold 1990; Bishop, Rands, and Holley 1982). Changes in the neutron spectra (caused by changes in the power of the reactor) or changes in the instrumentation will affect the resulting ratios. Finally, the previous study utilized univariate T-tests to characterize the elemental composition of sample groups. Such tests do not explicitly characterize the distributions of elemental concentrations because sample groups are not described by a single set of elemental concentration values, but rather by a distribution of intercorrelated concentrations (see Bishop and Neff 1989; Neff, Bishop, and Arnold 1990).

Weaknesses of the earlier study must be placed in historical context. The previous analyses were carried out at the Penn State reactor facility from 1970 to 1972, a time when the techniques of INAA were undergoing development and analysts were working in isolation from their colleagues in other laboratories (Harbottle 1982:68). At Brookhaven National Laboratory, where the analyses reported here were done, standardized procedures (described in Bishop, Harbottle, and Sayre 1982) were developed in the mid-to-late 1970s that yielded highly precise and reproducible results (Harbottle 1982; Yeh and Harbottle 1986). Sufficiently long counting times along with use of a series of standard reference materials are crucial to avoid the problems encountered in the earlier study.

Results

In most studies of compositional analysis of pottery, researchers have usually worked with ancient pottery, and the location and procurement variables that produced it were unknown. In this study, we have controlled the behavioral variables and evaluate the chemical variability of contemporary pottery and its constituent raw materials (clay and temper) at a particular point in time—the present.

The questions and propositions we examine are drawn from two sources: (1) previous studies of compositional analysis of pottery, which relate pottery to its constituent raw materials, and (2) technological and ethnographic studies of pottery. In brief, we intend to show how samples collected with known behavioral variables (such as community of origin, effect of added temper, clay source, temper source) relate to the chemical data obtained by neutron activation analysis.

The Whiteware Tradition of Chinautla, Sacojito, and Durazno

Can ceramics be matched to specific raw materials? Probably the most common assumption underlying the neutron activation analysis of pottery is that the elements in fired pottery reveal the composition of the source materials used to make it. In the absence of tempering or other contamination, one expects the distribution of elemental concentrations in a group of ceramics to overlap with the distribution of elemental concentrations in a group of raw clays that come from the same deposit as the clay used to make the pottery.

When the potter adds temper to her clay, her ceramics will bear one of two logically possible relationships to the clay. Either (1) the ceramics will not match either the clay or the temper or (2) the ceramics will match *both* the clay and the temper. Even when an elementally impoverished temper is added to clay, it lowers the concentration of all elements in the ceramics so they will not match corresponding concentrations in clays (possibility No. 1). Possibility No. 2 would only occur if the temper and clay were compositionally identical.

Comparing the mean elemental concentrations of temper, clay, and pottery reveals great differences between pottery, on the one hand, and clays and tempers, on the other (Table 1). Most of the mean elemental concentrations in whitewares made in each community differ from their constituent clays and tempers and do not overlap at one standard deviation. The mean elemental concentrations of the Sacojito and Chinautla whitewares differ from those of the Chinautla/Sacojito source clays and from the volcanic ash tempers from these communities. Further, the mean concentrations of the whitewares from Durazno differ from those of the source clay and volcanic ash temper from this community. Thus, based on the concentration means and standard deviations (Table 1), tempered ceramics cannot be matched to single, specific sources of raw material. Whiteware ceramics from Chinautla, Sacojito, and Durazno do not match the composition of the constituent whiteware clays or of volcanic ash temper from these communities.

If whitewares cannot be related to individual constituent clays or constituent tempers, can they be related to mixtures of their constituent raw materials? Since the elemental concentrations of clays and tempers are different from the fired pottery, it is likely that the composition of pottery expresses the proportional mixtures of temper and clay mixed by the potter. Indeed, the ceramics should express the composition of both the clay and the temper mixed in the preparation of the ceramic paste. The elemental concentrations in mixtures of clays and tempers (S_i) can be calculated from the elemental concentrations of temper and those of clay. By mixing the elemental concentrations of clay (C_i) and temper (T_i) according to the proportions of clay (P_c) and temper (P_t) in the mixture, one can devise the following formula to express concentrations in the mixtures: $S_i = P_t (T_i) + P_c (C_i)$, where $P_t + P_c = 1$. By using this formula with the elemental concentrations of clays and tempers, the elemental concentrations of mixtures for hypothetical pottery can be calculated and then matched with the elemental concentrations in the whiteware ceramics. Rather than calculating the elemental concentrations in all possible mixtures of clay and temper, proportions most likely to match the ceramics can be chosen by maximizing the average multivariate probability that the whiteware ceramics belong to a hypothetical group formed by "mixing" clays according to the above formula.[2] One can then examine only the mixtures most likely to have elemental concentrations that match the real whiteware ceramics.

Table 1
Elemental concentration means and standard deviations for clays, tempers, and pottery for Chinautla, Sacojito, and Durazno.

	Chinautla/Sacojito clay (n = 17)		Durazno clay (n = 7)		Volcanic ash temper (n = 32)		Chinautla pottery (n = 13)		Sacojito pottery (n = 13)		Durazno pottery (n = 26)	
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
K	12,951.0	2,728.4	7,461.9	3,547.6	29,108.0	1,922.8	19,505.2	1,840.4	21,166.4	1,662.2	17,402.9	4,107.5
Sc	19.4	1.8	18.5	3.1	3.3	0.4	15.1	1.7	15.3	1.5	18.6	2.1
Cr	61.7	8.4	19.9	6.5	2.4	1.4	46.1	10.0	46.7	8.9	21.3	10.7
Fe	26,640.5	2,216.7	43,231.6	19,870.3	8,264.8	1,275.7	24,685.0	4,586.1	24,283.3	4,011.3	26,368.9	3,837.3
Zn	138.6	20.2	91.1	16.6	30.9	19.4	102.6	19.8	111.7	23.2	95.5	25.0
Rb	159.5	12.7	73.2	34.0	130.4	5.9	153.1	17.0	158.5	11.2	99.2	12.2
Cs	9.8	1.1	5.2	1.3	5.4	0.7	8.8	1.5	8.8	1.1	5.5	0.7
Ba	396.2	67.4	627.4	136.8	1,039.2	35.9	729.5	78.5	728.8	75.8	783.3	61.8
La	26.2	5.0	24.7	7.5	22.7	4.9	29.2	3.5	28.8	2.5	27.6	3.0
Ce	48.7	9.4	46.7	8.8	35.1	6.2	51.8	5.4	50.9	4.7	44.9	3.3
Sm	6.4	1.3	5.4	1.6	2.7	0.4	6.1	0.6	6.0	0.6	5.9	0.8
Eu	1.2	0.2	1.2	0.3	0.4	0.1	1.1	0.1	1.1	0.1	1.2	0.2
Yb	3.2	0.6	3.2	0.8	1.5	0.2	3.2	0.3	3.1	0.3	3.6	0.5
Lu	0.41	0.08	0.43	0.12	0.20	0.02	0.39	0.04	0.40	0.06	0.48	0.08
Hf	3.7	0.5	6.2	1.5	3.1	0.4	4.1	0.6	4.1	0.6	5.3	0.6
Ta	0.7	0.1	0.6	0.1	0.5	0.1	0.7	0.1	0.8	0.2	0.6	0.1
Th	9.2	1.1	7.2	0.8	11.2	1.2	11.4	1.0	11.3	0.6	9.6	0.5

In order to reject the hypothesis that tempered ceramics can be related to their constituent raw materials, there must be no possible mixtures of volcanic ash temper and Chinautla/Sacojito white clay that define a range of compositional variability that would include the Chinautla/Sacojito whiteware ceramics.

The average multivariate probability (based on Hotelling's T^2) comparing elemental concentrations of sherds with mixtures of clays and tempers shows that the real whiteware ceramics match the hypothetical mixed groups formed by "mixing" clay from the Chinautla/Sacojito source and volcanic ash in a proportion of approximately 60:40 (Figures 2 and 3). For the Sacojito sherds (Figure 2), peak probabilities of 25% occur in the range of 40%–50% temper. Chinautla sherds do not show peak probabilities quite as high as the Sacojito sherds, and there may be a tendency for them to peak at slightly lower tempering proportions (Figure 3). Clearly, mixtures of about 40%–50% temper with white clay match the Chinautla and Sacojito ceramics much more closely than does either the clay or the temper alone. The plots for Chinautla and Sacojito sherds contrast dramatically with the plots for Durazno sherds (Figure 4), which peak near 100% temper at infinitesimally small probability values. Durazno whitewares thus resemble pure volcanic ash temper more closely than they resemble any mixture of temper with clay from the Chinautla/Sacojito source. This finding coincides with the ethnographic observation that potters from the three communities use a basically uniform temper, but they add it to two very distinct clays (the black clay from Durazno and the white clay from the Chinautla/Sacojito source). (Curves for the Durazno raw materials analogous to the curves for Chinautla/Sacojito clays and tempers are not available because the total number of clay specimens from Durazno [$N = 7$] is lower than the number of variates [17], so the variance-covariance matrix is singular, and the multivariate probability calculations are therefore impossible.)

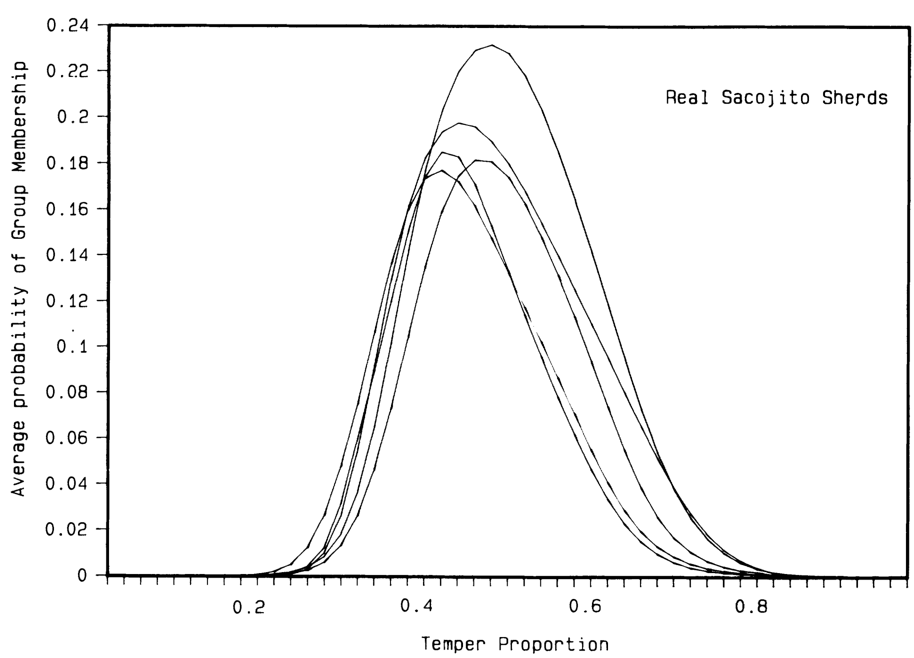

Figure 2
The average multivariate probability (based on Hotelling's T^2) that the real Sacojito whiteware ceramics belong to hypothetical groups formed by mixing clay from the Sacojito/Chinautla source and volcanic ash in proportions ranging from 0% to 98% temper. (Five separate runs of the experiment are shown.)

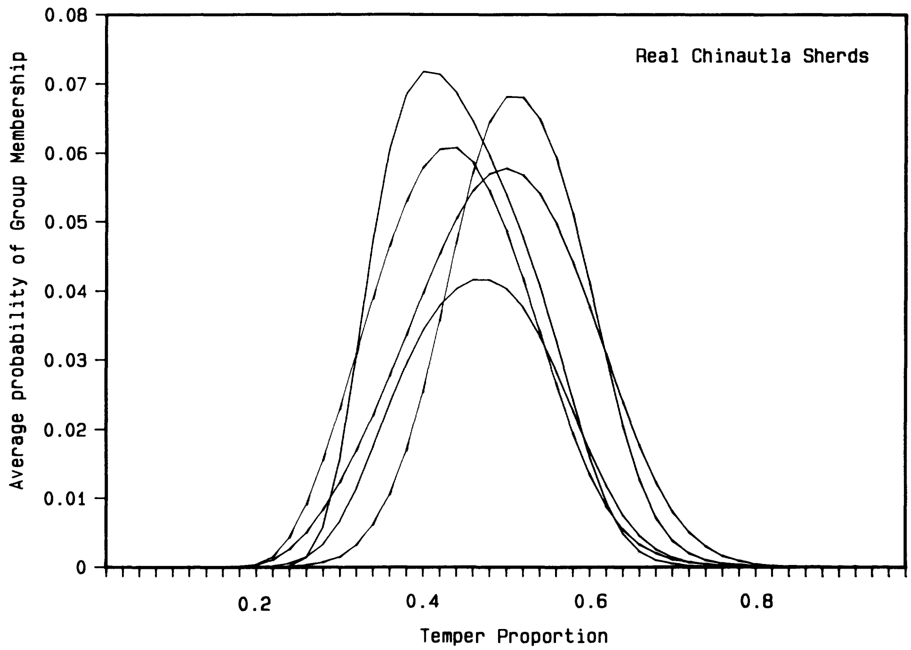

Figure 3
The average multivariate probability (based on Hotelling's T^2) that the real Chinautla whiteware ceramics belong to hypothetical groups formed by mixing clay from the Sacojito/Chinautla source and volcanic ash in proportions ranging from 0% to 98% temper. (Five separate runs of the experiment are shown.)

The elemental concentration means and standard deviations for the hypothetical mixtures of 40% temper show a greater overlap with the real sherds than with their constituent raw materials of clay and temper (Table 2). However, there are still substantial differences in many elements. This pattern suggests that the clay samples from the Chinautla/Sacojito and Durazno sources do not adequately characterize the range of variability actually sampled by potters when they mine clay for the production of pottery. This interpretation is virtually *required* by the small number of specimens in each of our samples.

Still, we cannot rule out the possibility of contamination from the other sources. Elements that form mobile cations, such as potassium (K) and barium (Ba), may exist in solution in groundwater (see Bishop 1980), so differences between the real sherds and the hypothetical mixtures may be due partially to the fact that the hypothetical mixtures do not allow for contamination by the water that the potter mixes with the clay. Alternatively, potters may have added other unidentified contaminants to the paste, although there are no ethnographic data to support such a possibility.

The relationship between the raw clays, ceramics, and tempers can be demonstrated concisely by a discriminant analysis of the Durazno raw clay, the Chinautla/Sacojito raw clays, and all tempers (Figure 5). Discriminant analysis (see, for example, Davis 1986) calculates reference axes that maximally separate the known groups (two clays and tempers). When the tempered ceramics are projected into this space, their positions are, as expected, intermediate between the tempers and the clays from which they were derived.

In summary, despite lack of a one-to-one correspondence between pottery and clay, on the one hand, and pottery and temper on the other, the neutron activation data show that the ethnographic whiteware ceramics of the northern Valley of Guatemala were indeed

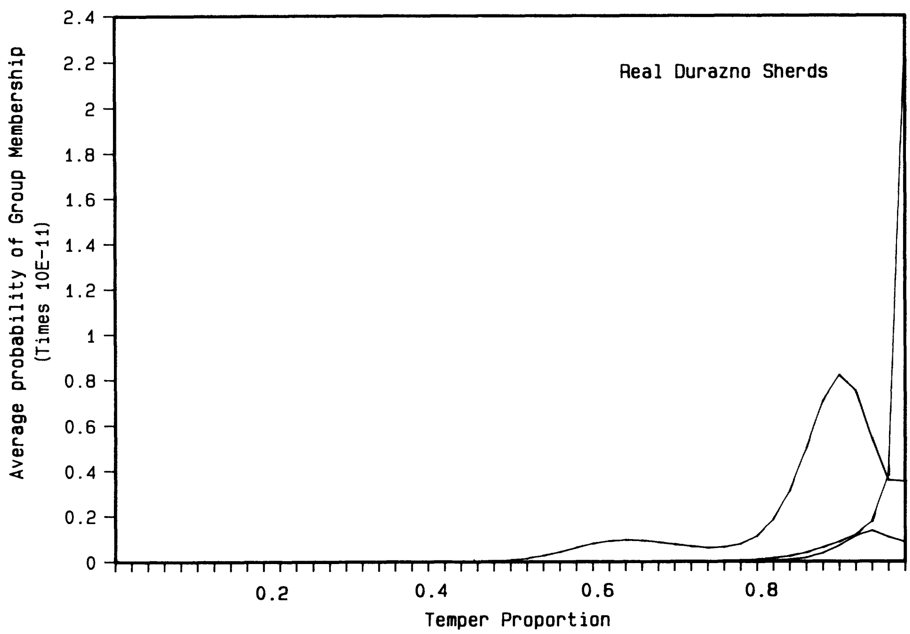

Figure 4

The average multivariate probability (based on Hotelling's T^2) that the real Durazno white-ware ceramics belong to hypothetical groups formed by mixing clay from the Sacojito/Chinautla source and volcanic ash in proportions ranging from 0% to 98% temper. (Three separate runs of the experiment are shown.)

made from mixtures of certain clays and tempers mined in the valley. These findings indicate that tempered ceramics reflect the weighted proportions of clay and temper in potters' recipes (Figures 2–4; Table 2). The possibility that additional sources of contamination may exist is left open.

What is the nature of compositional variability within a single ceramic tradition? Having demonstrated that tempered ceramics can be related to their constituent raw materials, the nature of compositional variability within a ceramic tradition will now be examined. The whiteware tradition of the northern Valley of Guatemala is shared by potters in the Pokomam-speaking communities of Chinautla, Sacojito, and Durazno (Arnold 1978a, 1978b). Vessel forms are shared by potters in all three communities. Although paste preparation practices are similar among the three villages, resource procurement overlaps only partially. Chinautla and Sacojito potters procure clay from a single mine, while Durazno potters utilize a distinct set of closely spaced pits within the community. Potters exploit temper sources close to their communities, consisting of three basic zones of temper procurement. All temper sources are, however, within a widespread volcanic ash stratum that blankets the northern Valley of Guatemala.

How accurately does compositional analysis reflect the true resource procurement situation? Knowing that the ceramics come from three separate communities might tempt one, without knowing anything about clay procurement practices, to suggest that three rather than two separate sources are involved. Discriminant analysis of the log-transformed data, however, shows that while Durazno ceramics are easily separated from both Chinautla and Sacojito ceramics, the Chinautla and Sacojito ceramics overlap almost completely. This finding coincides with the ethnographic observation that potters in the two communities do, in fact, use the same clay source and that all temper sources are

Table 2
Elemental concentration means and standard deviations for real and hypothetical mixtures of clay and tempers from the northern Valley of Guatemala.

	Chinautla pottery (n = 13)		Sacojito pottery (n = 13)		Chinautla/Sacojito 60/40 mixtures		Durazno pottery (n = 26)		Durazno 60/40 mixtures	
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
K	19,505.2	1,840.4	21,166.4	1,662.2	19,582.8	2,482.3	17,402.9	4,107.5	16,173.1	3,583.5
Sc	15.1	1.7	15.3	1.5	13.5	2.1	18.6	2.1	12.6	2.7
Cr	46.1	10.0	46.7	8.9	40.0	8.6	21.3	10.7	13.4	5.3
Fe	24,685.0	4,586.1	24,283.3	4,011.3	20,112.7	2,802.2	26,368.9	3,837.3	27,026.2	9,436.4
Zn	102.6	19.8	111.7	23.2	98.8	16.3	95.5	25.0	67.6	14.6
Rb	153.1	17.0	158.5	11.2	151.1	9.4	99.2	12.2	98.1	22.9
Cs	8.8	1.5	8.8	1.1	8.4	1.0	5.5	0.7	5.2	0.8
Ba	729.5	78.5	728.8	75.8	647.7	72.5	783.3	61.8	789.5	97.7
La	29.2	3.5	28.8	2.5	25.0	4.1	27.6	3.0	25.4	5.2
Ce	51.8	5.4	50.9	4.7	43.8	7.5	44.9	3.3	43.1	6.2
Sm	6.1	0.6	6.0	0.6	5.1	1.1	5.9	0.8	4.5	1.1
Eu	1.1	0.1	1.1	0.1	0.9	0.2	1.2	0.2	0.9	0.2
Yb	3.2	0.3	3.1	0.3	2.6	0.6	3.6	0.5	2.7	0.6
Lu	0.39	0.04	0.40	0.06	0.3	0.1	0.5	0.1	0.4	0.1
Hf	4.1	0.6	4.1	0.6	3.5	0.4	5.3	0.6	4.9	0.9
Ta	0.7	0.1	0.8	0.2	0.7	0.1	0.6	0.1	0.6	0.1
Th	11.4	1.0	11.3	0.6	10.1	0.9	9.6	0.5	8.8	0.9

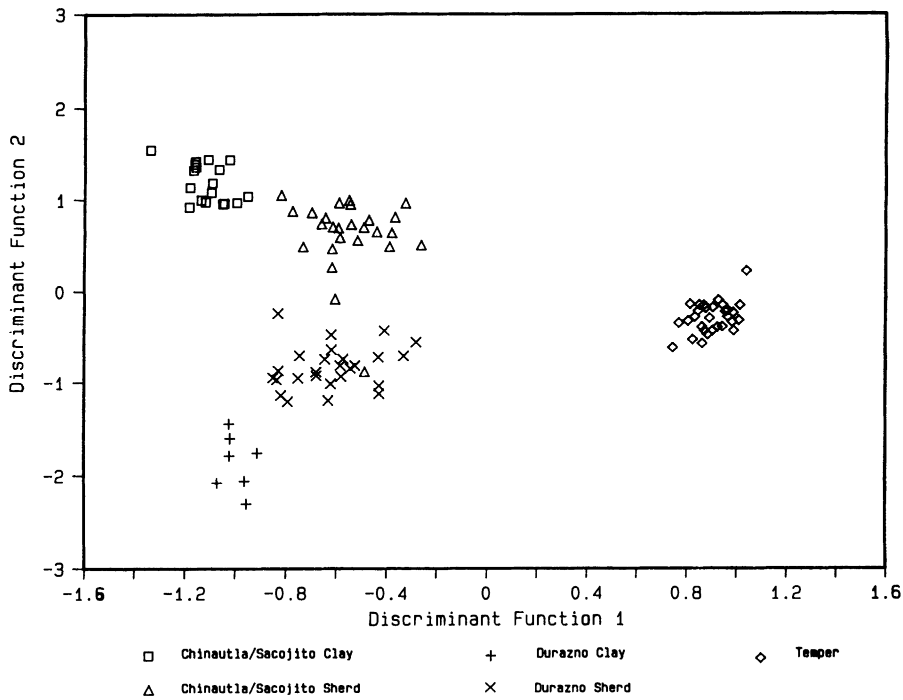

Figure 5
Plot derived from discriminant analysis of Chinautla/Sacojito whiteware source clays (N = 17), Durazno whiteware source clays (N = 7), and all volcanic ash tempers (N = 32). Chinautla/Sacojito sherds (N = 26) and Durazno sherds (N = 26) are projected into the raw material discriminant space by multiplying their elemental concentrations by the coefficients derived from the discriminant analysis of the raw material (see Davis 1986).

located within a single widespread ash blanket that, without further research, appears to be geologically and geochemically uniform.

A discriminant analysis based only on the clays succeeds in separating the samples from the two communities, but this is a chance result explained by small sample sizes involved. One would not expect to find separation of clays from the communities to occur consistently over time. In further support of this contention, the supposed dimension of maximum separation between Chinautla and Sacojito (discriminant function 2 in this analysis) does not separate ceramics from the two communities at all, as indicated by the positions of ceramics from the two communities projected into discriminant space.

One might expect a slight tendency for tempers from the three communities to differ slightly, simply because potters in each community exploit different locations within the Valley of Guatemala ash blanket. This expectation derives from the observation that the composition of highland Guatemalan volcanic ash varies in composition, both laterally within a single stratigraphic unit (Rose, Grant, and Easter 1979; Hahn, Rose, and Meyers 1979) and vertically from one stratigraphic unit to the next (Drexler et al. 1980). Although the distributions of elemental concentrations (summarized in Table 3) do not suggest significant differences among the three temper source zones, a discriminant analysis does succeed in separating the three groups. Caution must be exercised in this case because, as mentioned above, the small sample size renders it likely that some linear combination of the original variates will, in fact, separate the three groups. Furthermore, like the ceramics from Chinautla and Sacojito, the differences in temper sources do not trans-

Table 3
Elemental concentration means and standard deviations in volcanic ash temper from pottery-making communities in the northern Valley of Guatemala.

	Chinautla (n = 7)		Sacojito (n = 10)		Durazno (n = 23)	
	Mean	S.D.	Mean	S.D.	Mean	S.D.
K	20,827.7	14,247.5	25,966.8	9.253.4	27,756.9	8,853.1
Sc	3.0	0.3	3.4	0.2	3.4	0.4
Cr	2.0	0.4	2.2	0.6	2.9	2.1
Fe	7,710.9	919.2	8,337.6	857.5	8,606.4	1,689.1
Zn	26.9	5.2	28.2	1.4	36.2	30.4
Rb	127.5	6.6	129.2	6.1	133.0	4.8
Cs	5.7	0.4	5.0	0.7	5.6	0.8
Ba	1,028.2	44.1	1,041.6	25.9	1,041.3	40.4
La	19.8	0.8	23.6	4.5	23.6	6.2
Ce	31.3	1.7	35.5	5.9	37.1	7.6
Sm	2.6	0.3	2.7	0.3	2.7	0.6
Eu	0.4	0.1	0.4	0.1	0.4	0.1
Yb	1.6	0.2	1.6	0.1	1.5	0.2
Lu	0.20	0.02	0.20	0.02	0.20	0.03
Hf	2.9	0.3	3.2	0.4	3.2	0.4
Ta	0.5	0.0	0.5	0.1	0.5	0.2
Th	10.6	0.5	11.2	1.0	11.5	1.5

late into a consistent compositional difference between the ceramics produced in the two communities.

The Redwares Produced in the Valley of Guatemala

A total of 37 redwares from contemporary communities in the Guatemala highlands were analyzed. These represent seven communities with the maximum of eleven analyses from one community (Mixco). The small sample size reflects the lower production of this ware relative to the whitewares and the small number of potters producing it in Chinautla, Sacojito, Durazno, Sacoj, and Mixco. Although the small sample sizes preclude formation of community-based reference groups, an overall assessment of variability within the whole collection of redware analyses provides fairly clear evidence that intercommunity compositional distinctions exist.

Can redwares from various parts of the highlands be differentiated? There is considerable heterogeneity in the elemental concentrations within the group of redwares. This can be demonstrated by a principal-components analysis of the logged elemental concentration data for Chinautla/Sacojito and Durazno whitewares along with 35 of the redwares. Unlike discriminant analysis, which calculates reference axes to achieve maximal separation between groups that are assumed to exist in their data, principal-components analysis merely reorients the reference axes so that each axis accounts for successively less variance in the data (Davis 1986). Interpoint relationships are preserved on the new axes.

A plot of the first two principal components (i.e., the dimensions of greatest variance) of the combined data set (Figure 6) shows that redwares are dispersed over a much larger region of compositional space than the two distinct whiteware groups already identified. The heterogeneity within the redware group as a whole suggests that the subgrouping of the samples may be related to specific procurement locations.

A principal-components analysis of the 35 redwares and constituent clays reveals the subgroups more clearly. The 11 Mixco clays and redwares form a discrete group that is fully separable from all other groups on the first two principal components alone (Figure 7). Likewise, Chinautla redware analyses form a discrete group, although one redware

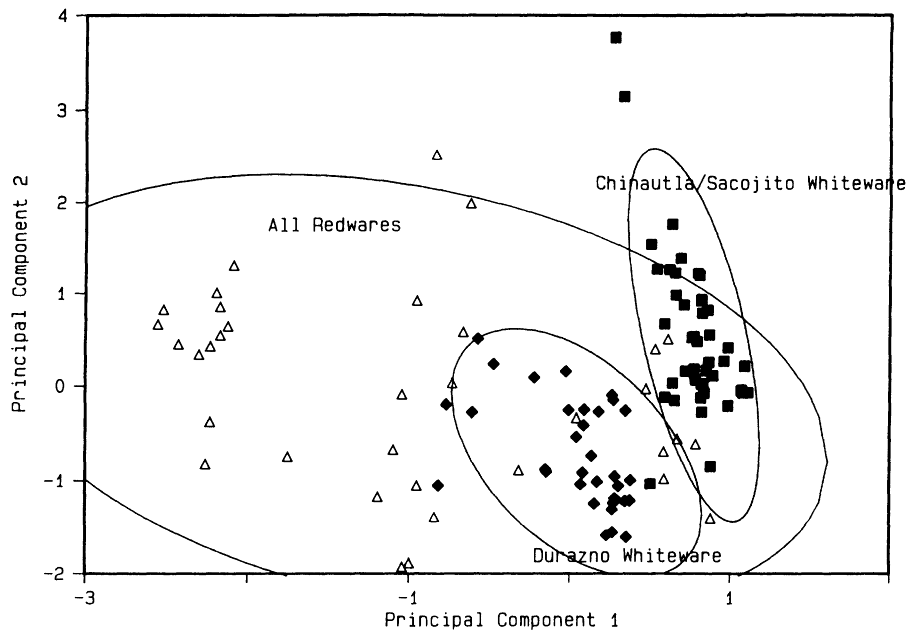

Figure 6

Plot of scores on principal components 1 and 2 of the data set consisting of all ethnographic whitewares and all ethnographic redwares collected in the Valley of Guatemala. Symbols differentiate Chinautla/Sacojito whitewares, Durazno whitewares, and redwares. Ellipses indicate the 90% probability level for group membership based only on the two dimensions plotted.

sherd from Sacojito and one from Sacoj fall within the 90% probability ellipse for this group on the first two principal components. Chinautla is close enough to these communities that potters could have brought either the redware clays or the redware vessels themselves from Chinautla (see Arnold 1985:32–57; 1988).

The other Sacoj and Sacojito redwares form a group together with the La Cienaga sherd and one sample of Durazno paste. Four Durazno redwares also lie close to this third group on the plot. Four other Durazno analyses are outliers from all the other groups. Two sherds of cooking pots collected in the Chichicastenango market and thought to be from the town of Jocopilas (approximately 80 km north-northwest of the communities discussed here) are not shown on the plot; they are markedly divergent from all other redware samples.

The subgroups evident in the principal-components plot (Figure 7) include both raw clays and finished ceramics. The Mixco subgroup includes three sherds and seven raw clays, while the Chinautla subgroup includes two prepared pastes, three clays, and one sherd. The Durazno samples are all raw materials (clays and prepared paste) and sherds from cooking pots. The four Durazno samples near the top of the plot are all clays obtained near the potters' houselots, while the Durazno samples near the bottom of the plot are either sherds or pastes that have been tempered with volcanic ash and include three sherds, one clay, and one prepared paste. Although small sample sizes preclude drawing firm conclusions from the redware data, observations suggest that, as in the case of whitewares, redware ceramics can indeed be related to the raw material sources from which they were derived. Contamination with temper, groundwater, or other materials during the paste preparation procedure does not, apparently, obscure the resemblance of redware ceramics to the clay used in their manufacture.

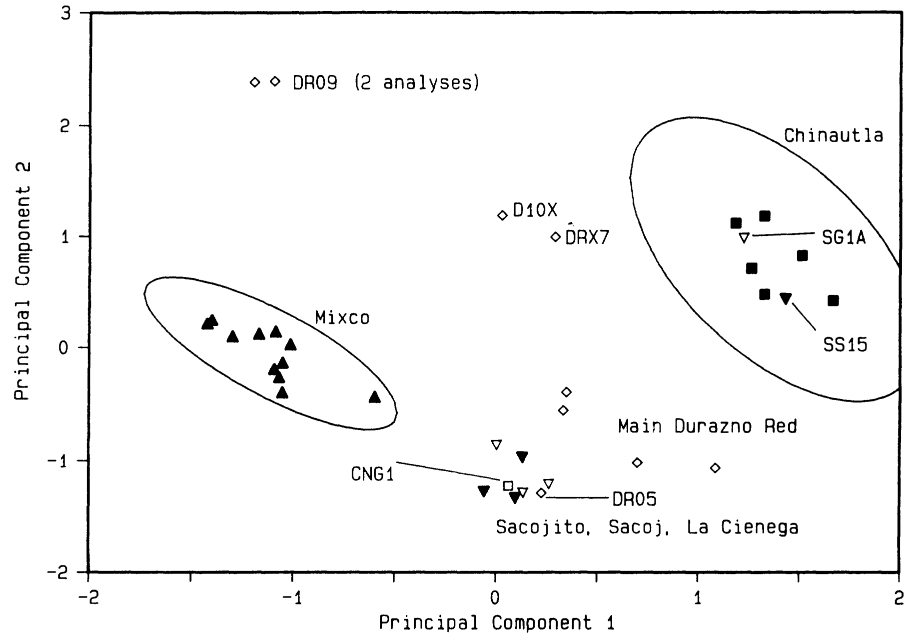

Figure 7
Plot of scores on principal components 1 and 2 of the data consisting of all ethnographic redwares (pottery and clay) collected in the Valley of Guatemala. Ellipses indicate 90% probability of group membership, based only on the two dimensions plotted.

General Regional Affiliations

Can a generalized profile of the region be formed that subsumes all the profiles of known contemporary compositional groups, yet excludes other, known nonlocal profiles? The previous discussion suggested that the notion of "source" is somewhat ambiguous. "Sources" can be conceived on different levels of geographical inclusiveness: region, community, and an individual pit or mine. On the most specific level, can ceramics be matched to raw material sources like pits or mines? In this case, can Chinautla and Sacojito whiteware be matched to the clay mine used by potters in the two communities? In the discussion of whitewares earlier in this article, we pointed out that tempered ceramics do not match a single clay pit or mine, but that their composition reflects all raw material components (clay and temper in this case) that were mixed in the preparation of ceramic paste. In short, the compositional profile of a ceramic encodes both natural and cultural information.

On a somewhat more inclusive level, can Chinautla/Sacojito and Durazno whitewares be matched to a more generalized "regional profile" for the northern Valley of Guatemala? Both the specific and the more general levels of source attribution may be important in an archeological application. Many, if not most, analyzed ceramics may not be attributable to precise sources like a pit or mine, but a more general regional attribution may be more relevant for the vast majority of analyzed specimens. This approach to compositional analysis may be called a "hierarchical approach" to source attribution and has been introduced previously in studies of compositional data from Pacific coastal and highland Guatemala (Neff 1984; Neff and Bishop 1988; Neff, Bishop, and Bove 1989).

A graphic representation of the "hierarchical approach" displays each source within higher levels of inclusion (Figure 8). All ceramics made within a hypothetical area (the shaded region in Figure 8) are derived from some specific set of raw material sources in the region. As mentioned earlier, ceramic pastes will probably not match the composition

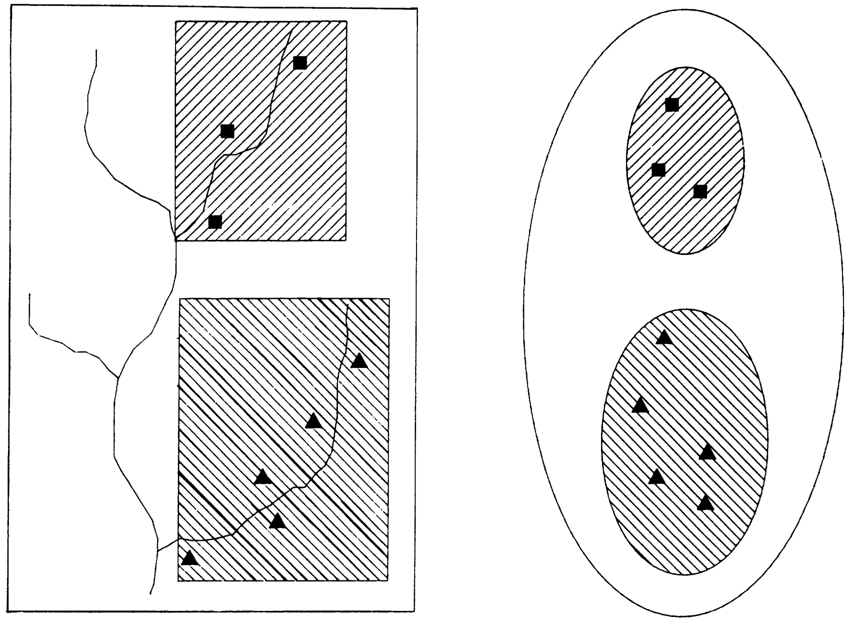

Figure 8
Schematic depiction of the hierarchical or nested model of compositional variability. *Left:* Hypothetical region with archeological sites located along two tributaries of a major drainage. *Right:* Schematic depiction of the range of compositional variability in pottery made in the region shown on the left. The two small ellipses within the larger ellipse indicate the range of compositional variability of pottery made within each of the tributary drainages, while the large ellipse indicates range of variability in all pottery from the region. The smaller ellipses subsume several specific sources, whose centroids are indicated by symbols.

of any single specific pit or mine due to the problem of mixing, although they may be related to specific sets of raw materials under ideal conditions. A generalized group, however, subsumes a large proportion of the variability of all raw materials within the shaded region, yet is not so generalized that it subsumes pottery from other zones as well. If these conditions are met, individual specimens that fall within the region of elemental concentration space occupied by the general group were probably produced within the hypothetical source region.

A typical application of this hierarchical approach might involve a question about whether several distinct compositional groups found to characterize the ceramics from a site were all produced in the region surrounding the site. Ethnographic data from a worldwide sample of resource distances have demonstrated that most potters travel no more than 7 km (Arnold 1985:38–42; 1988) to obtain their raw materials, and many go no more than 1 km. Thus, the pottery produced by any given community is drawn from constituent raw materials that occur within a universal "resource area" that has a radius of 7 km. A first step toward characterizing such a resource area would be to define a generalized compositional profile for the region. This profile might be compiled from analyses of raw materials collected within 1 km of this site and others collected not more than 7 km from the site, from ceramics that have a high prior probability of being found in their source region (i.e., common, utilitarian wares), or from a combination of ceramics and raw materials. Ideally, such a general group is (a) broad enough to subsume the compositional profiles of all or at least most ceramic resources present within the region and (b) not so broad that it also subsumes compositional profiles that are characteristic of other regions. Specimens to be projected against the general group would, of course, be excluded from initial membership in the group. Whether it is possible to construct such a compositional group for some particular region is an empirical, not a theoretical matter, and must be assessed on an ad hoc basis for specific regions.

To illustrate this approach using the present data, a 200-specimen "generalized northern Valley of Guatemala ethnographic group" was formed from all the clay samples used to make redwares and whitewares in the area, along with artificial mixtures of red and white clays and artificial mixtures of all the clays with 30% (10% S.D.) volcanic ash temper. This group represents the total range of the raw materials utilized by contemporary potters in the northern Valley of Guatemala.

Projecting the Chinautla, Sacojito, and Durazno whiteware sherds onto the first two principal components of a "general contemporary Valley of Guatemala group" reveals that the sherds from the two distinct whiteware groups occur within the area of the more generalized group (Figure 9). Ellipses enclosing the 90% confidence level of the generalized group and both of the whiteware groups are also plotted, and these further emphasize the nested structure of variability within the effective ceramic environment exploited by the contemporary Valley of Guatemala potters.

Group membership cannot, of course, be reduced to a consideration of two dimensions alone when variability was originally measured along multiple dimensions (13 elements were utilized in this case, rather than the 17 reported in the previous examples). The dispersion-corrected distances (Mahalanobis distances, which have associated probabilities derived from an F-distribution) from the general group centroid form the basis for

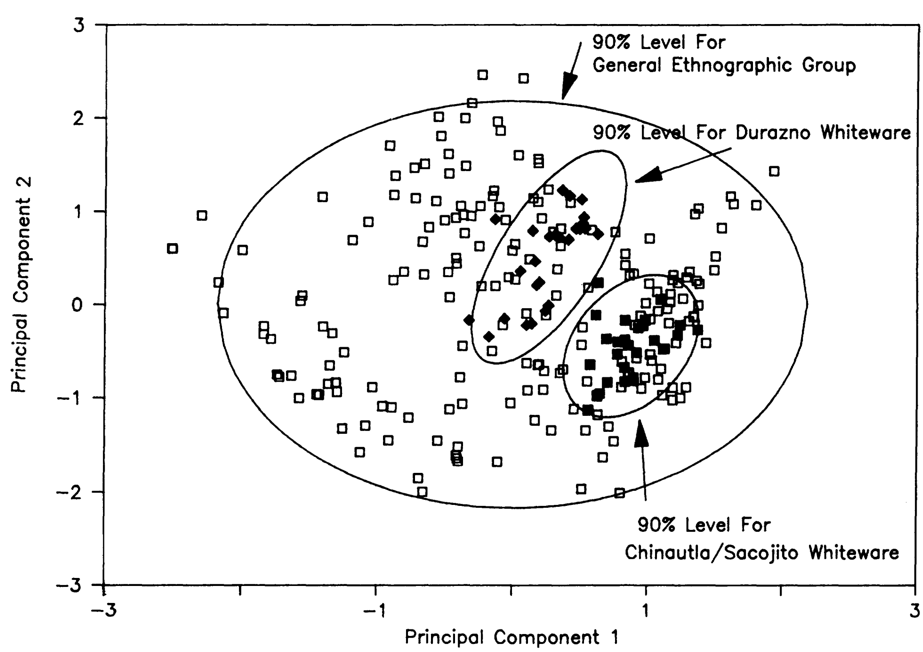

Figure 9
Hierarchical compositional variability in ethnographic ceramics and raw materials from the northern Valley of Guatemala, as expressed on the first two principal components of a generalized group consisting of all analyzed specimens plus artificial mixtures. Locations of the Chinautla/Sacojito and Durazno whitewares are distinguished; 90% levels for the general group and for the Chinautla/Sacojito and Durazno whitewares are indicated.

true multivariate assessment of the likelihood that each individual sample is a member of the reference group (i.e., the general ethnographic group in the present case). As an additional test of the usefulness of the hierarchical approach to compositional data, probabilities of membership in the general ethnographic group were obtained for the Chinautla/Sacojito whiteware sherds, the Durazno sherds, and a group of pre-Hispanic Tohil Plumbate specimens (Tohil Plumbate is a kind of pottery that was produced during Late Classic and Early Postclassic times on the Pacific coastal plain of southern Mexico and southwestern Guatemala [Neff 1984; Neff and Bishop 1988]). Probabilities of membership in the regional group for the two modern whiteware groups are overwhelmingly above 20%, while probabilities for the Tohil Plumbate specimens are overwhelmingly below 0.01%. In sum, a hierarchical perspective of the compositional data leads to a correct behavioral interpretation, namely that the prehistoric Plumbate potters exploited a ceramic environment distinct from that exploited by the modern potters in the northern Valley of Guatemala. While this method matches the cultural and behavioral variables nicely, further research using this hierarchical approach will have to be carried out in order to test its general usefulness.

Conclusion

Compositional data derived from ceramics cannot be used in a simpleminded search for the clay source exploited by ancient potters. Instead, middle-range theory must be developed that explicitly relates compositional profiles of raw materials, on the one hand, with cultural conventions governing resource selection and paste preparation, on the other. This article contributes to such middle-range theory by applying compositional analysis to an ethnographic setting in which raw material sources as well as cultural practices involved in paste preparation are known.

Our results demonstrate that the basic assumption underlying neutron activation analysis of archeological materials from the beginning (e.g., Sayre and Dodson 1957) is sound: elemental concentrations in pottery *do* reflect the elemental concentrations in source materials. However, acceptance of this basic proposition must not obscure the fact that "source" is a complex notion.

First, a source can be conceived on various levels of geographical inclusiveness, from the level of specific clay mine to the level of resource catchment zone or region. The whitewares made in Chinautla and in Sacojito are made from clay from a single mine, and from temper from a variety of chemically similar sources. Whitewares from both communities show virtually identical compositional profiles. Furthermore, the Chinautla/Sacojito whiteware does not come from the same clay mine as the Durazno whiteware, but, on a regional level, both can be matched to a general compositional profile for the northern Valley of Guatemala. Investigators utilizing compositional analysis must specify the levels of geographical inclusiveness pertinent to the specific questions they are asking, and design sampling strategies accordingly.

Second, "matching" analyzed ceramics to source materials is not a matter of comparing the elemental composition of ceramics to that of the clays or the tempers, in a one-to-one manner. Instead, all "sources" are characterized by a range of intercorrelated elemental concentrations that are described by their central tendency (centroid) and dispersion (variance-covariance matrix). Ceramics for which a source attribution is desired must be compared to sources characterized in terms of these parameters. Simple proximity on a dendrogram or univariate comparison of elemental concentrations is insufficient. There are practical as well as theoretical reasons for this point of view. As Harbottle (1988) has demonstrated, taking the distributional characteristics of the data into consideration significantly enhances the ability to differentiate between source-related groups. This rule applies whether a match is desired with a highly localized mine or a more generalized source region.

Finally, the results show that the composition of ceramics does not just reflect the composition of some specific raw material source, but is in part determined by cultural practices involved in paste preparation. Potters usually temper, levigate, or otherwise prepare clay, and these practices affect elemental concentrations in the ceramic paste. In the present study, volcanic ash temper clearly contributes to the compositional profile of ceramics made from the Chinautla/Sacojito white clay source. Furthermore, whiteware ceramics show high probabilities of membership in a group formed from artificial mixtures of white clay and volcanic ash. While no "match" between the whiteware ceramics and a specific "source" of a constituent raw material is possible, it is possible to show that the ceramics were made of a mixture of specific raw materials available in the northern Valley of Guatemala. Forming artificial mixtures of raw material components available in a region may be a useful means of forming reference groups to which archeological ceramics could be compared (Neff, Bishop, and Sayre 1988, 1989).

This article thus supports a notion that "source" or provenience has important chemical and behavioral (cultural) components and pottery thus encodes both chemical information from the source and behavioral information from the potter. In spite of the problems of relating pottery to its constituent raw materials, pottery made in the same community and drawn from the same set of sources would thus be expected to be similar in chemical composition.

Notes

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[1]Rice (1977, 1978a, 1978b) made detailed analyses of several clays from this area using a variety of analyses, including neutron activation analysis. Whereas Rice collected her samples at the sources (in 1973–74), the samples employed in the present study were collected primarily from the potters. In addition, the present study is based on a larger sample size.

[2]All multivariate statistical calculations were carried out on elemental concentrations expressed as base 10 logarithms (see Bishop and Neff 1989 for a discussion of the data transformations).

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