Methodological Issues in the Provenance Investigation of Early Formative Mesoamerican Ceramics

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A recent study of Early Formative Mesoamerican pottery by instrumental neutron activation analysis (INAA) yielded surprising results that prompted two critiques in the *Proceedings of the National Academy of Sciences*. The INAA study indicated that the Olmec center of San Lorenzo was a major exporter of carved-incised and white pottery and that little if any pottery made elsewhere was consumed at San Lorenzo. The critiques purport to “overturn” the INAA study and demonstrate a more balanced exchange of pottery among Early Formative centers. However, the critiques rely on a series of mistaken claims and misunderstandings that are addressed here. New petrographic data on a small sample of Early Formative pottery (Stoltman et al. 2005) are potentially useful, but they do not “overturn” INAA of nearly 1000 pottery samples and hundreds of raw material samples.

Una investigación reciente de la cerámica del período Formativo Temprano de Mesoamérica se realizó por medio de análisis a través de activación de neutrones (NAA). El estudio produjo resultados sorprendentes, que provocaron dos críticas que fueron publicados en la revista *Proceedings of the Nacional Academy of Sciences*. El estudio por NAA indicó que el centro Olmeca de San Lorenzo exportaba cantidades apreciables de cerámica tallada-incisa y de pasta blanca, pero que la cantidad de cerámica producida en otras regiones que llegaba a San Lorenzo no alcanza el nivel de detección. Las críticas supuestamente anulan el estudio por NAA y demuestran un patrón de circulación de cerámica más equilibrado entre los centros del Formativo Temprano. Sin embargo, las críticas dependen en una serie de errores y faltas de entendimiento que se explica aquí. Nuevos datos petrográficos obtenidos de una muestra pequeña de la cerámica del

Formativo Temprano (Stoltman et al. 2005) son potencialmente de interés, pero no anulan los resultados de NAA de casi 1000 tiestos y cientos de muestras de barros crudos.

The nature of the Gulf lowland Olmec, whose Early Formative center at San Lorenzo, Veracruz, Mexico, thrived from approximately 1200 bc to 950 bc (uncalibrated), remains central to understanding early Mesoamerica. Both the level of socio-complexity of the San Lorenzo Olmec and the character of their interaction with contemporaneous societies continue to be debated. This debate has often been summarized under the overly simplified and polarizing terms "mother culture" and "sister culture" (Diehl 2004; Hammond 1988), which, because of their historical importance, merit some clarification.

The Mexican artist and art historian Miguel Covarrubias (1942, 1957) first cast the Olmec in a generative role, suggesting that they created and inspired many aspects of Mesoamerican art and civilization:

> "[The Olmec] introduced a cult of deities of the rain, of the sky, and of the earth, and with it a form of incipient theocracy by which they dominated a large population of peasant serfs, the peoples of the Pre-Classic cultures, a system that later prevailed all over Middle America and replaced the simple communalistic system of small autonomous peasant villages" (Covarrubias 1957: 83).

Some modern researchers accept that the Gulf lowland Olmec participated asymmetrically in prestige relationships, but most do not consider the "mother culture" concept analytically useful. Researchers holding these views also acknowledge that the Olmec passed on a legacy, though they do not insist that the Olmec were the only ancestors of later Mesoamerican societies (Diehl 2004:189).

The importance of two-way interaction between Gulf lowland Olmec and groups in distant regions (Oaxaca) was first stressed in an important paper by Kent V. Flannery (1968). As elaborated more recently, the “sister-culture” (Hammond 1988) or *primus inter pares* view (Diehl and Coe 1996; Flannery and Marcus 2000) casts the Gulf lowland groups as roughly equivalent in socio-political complexity to their Early Formative neighbors (Flannery et al. 2005). This view denies San Lorenzo Olmec priority in the development and promotion of iconography associated with the distinctive Olmec art style. Instead, argue proponents of this view, an Olmec style, like other features of Early Formative Mesoamerican societies, arose out of competitive interaction among Early Formative groups (Flannery and Marcus 1994, 2000; Grove 1989). As Flannery and Marcus (2000: 33) state, “[i]t is the adaptive autonomy and frequent competitive interaction of such chiefdoms that speed up evolution and eventually make useful technologies and sociopolitical strategies available to all regions.”

Much of the evidence for interregional interaction of the San Lorenzo Olmec has come from stylistic analysis. While the Olmec are known for monumental sculptures, such as the colossal stone heads of San Lorenzo, many portable objects, especially ceramic vessels and figurines, are labeled Olmec style without direct support for a connection with the Gulf lowlands (Blomster 2002; Grove 1989). In particular, three types of ceramic vessels recognized at San Lorenzo (Coe and Diehl 1980) appear at widespread sites in Early Formative Mesoamerica. These include Calzadas Carved, Limón Incised, and Xochiltepec White (along with a variant, Conejo Orange-on-White). Until recently, no robust data existed to determine if these ceramics were locally made or reflect some degree of Gulf-lowland export.

Instrumental neutron activation analysis (INAA) at the University of Missouri Research Reactor (MURR) of 945 Early Formative pottery sherds has shown that a surprisingly large portion of pottery with Olmec motifs found outside the Gulf lowland Olmec heartland was made at or near the center of San Lorenzo (Figure 1), while the amount of pottery that moved in the opposite direction or among non-Gulf lowland centers was so low that it was not detected, despite the large size of the analyzed sample (Neff and Glascock 2002). A synthesis of these data was published recently in a peer-reviewed journal, *Science* (Blomster et al. 2005). Confidence in the inferences about interregional exchange produced by the study is warranted by the size of the sample of analyzed pottery, the inclusion of numerous raw material analyses, and the marked elemental differences among the sampled regions. Nonetheless, two recent articles in *Proceedings of the National Academy of Sciences* (*PNAS*) allegedly refute the major findings of the study. We are pleased to see this research generate such interest and welcome this opportunity to discuss the findings in more detail.

Blomster et al. (2005) focused on presenting the evidence for directionality in the movement of Early Formative ceramics. The evidence consists of regional source attributions for 725 of the analyzed Early Formative sherds (Table 1; Figures 2 - 5). Although the two critiques published in *PNAS* imply that a fairly radical pro-“mother culture” agenda drove the research, this was not the case. Obviously the pattern shown in Table 1 has implications for understanding the nature of interaction among Early Formative societies, some of which were discussed by Blomster et al. (2005). The overriding purpose of the article, however, was to publicize the new information so that it could inform future discussions of Early Formative interaction. Although we think the terms “mother culture” and “sister culture” have historical importance, the *Science* article (Blomster et al. 2005) attempted to move beyond this dichotomy, emphasizing the dominant role of the Olmec in exporting ceramics, while also noting the variability in consumption patterns among regions.

The first of the two critiques, by Stoltman, Marcus, Flannery, Burton, and Moyle (2005), presents results of a petrographic study of approximately 20 sherds that purportedly demonstrate export of ceramics from non-Gulf lowland centers. Stoltman et al. (2005) also carry out a statistical analysis of the MURR INAA data, on the basis of which they argue that the elemental data themselves demonstrate multi-way movement of Early Formative ceramics.

The second article, by Flannery, Balkansky, Feinman, Grove, Marcus, Redmond, Reynolds, Sharer, Spencer, and Yaeger (2005), contains no new primary data but offers an alternative statistical reanalysis of the MURR INAA data together with a broader condemnation of Blomster et al.’s (2005) views and those of others on the Olmec. Flannery et al. (2005) start from the premise that the results of the INAA study are “refuted by the petrographic thin-section analyses of Stoltman et al., …[which] is only the latest to indicate that INAA has serious limitations in tracing individual sherds to their source” (Flannery et al. 2005:11219). Given this dim view of the usefulness of INAA, it is worthwhile to point out that Spencer and Redmond are currently collaborating in a large INAA study of Late Formative Oaxaca pottery (Sherman et al. 2004), Redmond has used INAA of ceramics in the past (Redmond and Harbottle 1983), and Sharer likewise has relied on INAA results in other projects (Bell et al. 2004:134; Bishop et al. 1989; Sharer 2000). With such a wealth of experience using INAA in ceramic provenance investigations, the methodological misapprehensions of Flannery et al. (2005) are puzzling.

The contradictory findings of the petrographic and INAA studies deserve further exploration, and, in fact, Glascock has offered to analyze the petrographic samples by INAA at MURR expense. However, the errors and mischaracterizations of Stoltman et al. (2005) and Flannery et al. (2005) warrant a timely response regardless of the results of any future INAA study. Criticisms of INAA and the sampling design of the Olmec study are exaggerated and/or misleading, both statistical re-analyses are erroneous, and Blomster et al.'s (2005) views about Early Formative exchange are distorted and caricatured. With respect to the Flannery et al. (2005) article, we argue that archaeology is best served by an honest exchange of ideas and is ill served by inappropriate rhetorical tactics.

Before turning to issues raised by Stoltman et al. (2005) and Flannery et al. (2005) a brief explanation of the long list of authors' names attached to this article is warranted. Three of us (Blomster, Neff, and Glascock) were directly targeted by the authors of the *PNAS* articles. Beyond this, the other authors have varied expertise and concerns about issues raised by the *PNAS* articles. These include concerns about: distorted claims concerning weaknesses of INAA (especially Glascock, Bishop, Blackman, Neff, and Joyce); superficial and misleading statistical analyses (especially Cowgill, Neff, Bishop, Blomster, Glascock, and Lipo); distortion of arguments about cultural evolution in Formative Mesoamerica (especially Coe, Diehl, Stark, Cowgill, Blomster, Joyce, Winter, Neff, Houston); misconstrual of the relative merits and relationship between petrographic analysis and bulk elemental analysis (especially Blackman, Bishop, and Neff); and the nature of scientific debate (all coauthors).[1]

Previous Petrographic Research

Prior to the research reported in Blomster et al. (2005) and Neff and Glascock (2002) (as well as in preliminary versions [Blomster 1998a; Herrera et al. 1999]), no objective method for examining the movement of Early Formative pottery had been systematically implemented. Stoltman et al. (2005:11213) cite three previous mineralogical analyses that apparently anticipated their conclusion that pottery moved freely between highland sites and San Lorenzo. These earlier studies were exploratory. The earliest one, by Williams as part of Weaver's study of the Tlapacoya pottery in the Heye Foundation collection (Weaver 1967:29-30) consisted of two thin sections from the same Monte Albán tripod support (exact period not specified, but obviously post-Early Formative) that were compared with one Tlapacoya gray ware sherd. Weaver does not indicate if the Tlapacoya sherd is from a carved vessel. Because the collection studied by Weaver (1967:9) was "believed to have been excavated at Tlapacoya in 1962 by local *huaqueros*," who had already sold the whole vessels before the Heye Foundation acquired the materials she studied, no context or temporal information is available.

While the second study, by Lambert for Niederberger, also only examined two different vessels – one from Tlapacoya, one from Oaxaca (with somewhat ambiguous results [Flannery and Marcus 1994:262]) – the study by William O. Payne of 8 sherds from San Lorenzo merits some detailed comment. Flannery's project member Nanette Pyne went through the collection of Calzadas Carved pottery excavated by Coe and Diehl (1980) at San Lorenzo, and "instantly" noted motifs that were stylistically "Oaxaca-like"

(Flannery and Marcus 1994:263; Stoltman et al. 2005:11213); she removed pieces of the 8 sherds that appeared to be the most “Oaxaca-like.” No sherds were included that seemed local to San Lorenzo, so it appears no reference collection was available for comparative purposes.

Despite the ability of Pyne to “instantly” recognize “Oaxaca-like” ceramics at San Lorenzo, Payne subsequently rejected one sherd (SL-B4-9-EC) on the grounds that it had “no apparent relationship” to Oaxaca ceramics (Flannery and Marcus 1994:263). The other seven Pyne-Flannery samples ranged from being similar to Oaxaca gray wares (“could be of Oaxaca origin”) to identical (ibid.). Testing these sherds by INAA would be imperative. Unfortunately, no record was left at the Peabody Museum at Yale University, where the collection is curated, of the sherds from which Pyne removed samples. In their discussion of this material, Flannery and Marcus (1994:263) have never published illustrations of the sherds, nor have they linked them with the extensive ceramic illustrations in the San Lorenzo site report (Coe and Diehl 1980). The identification numbers provided by Stoltman et al. (2005) (several of which are invalid in the San Lorenzo numbering system) merely refer to the context in which the parent sherd was excavated. Thus, it is difficult to link these with the specific Calzadas Carved sherds in the Peabody Museum collection. This is especially problematic, as Payne’s microscopic examination of these sherds has served as the “hard evidence” for highland export of vessels to San Lorenzo, and they were re-used by Stoltman in the current study. It is possible that three of the eight Pyne-Flannery samples are included in the Blomster et al. (2005) sample (and were determined to originate at San Lorenzo by INAA), but, unfortunately, existing records - and incomplete publication and illustration of these sherds by Pyne-Flannery - preclude certainty in this matter.

The Samples Analyzed by INAA and Petrography

Flannery et al. (2005:11219) criticize the sampling design employed in the Olmec study,[2] alleging that "[i]t is hard to see this sample as anything but an attempt to make the bulk of San Lorenzo's pottery appear "local" and to minimize the chances of finding foreign sherds misclassified as Calzadas Carved." The basis for this claim is the alleged overemphasis of local utilitarian sherds at San Lorenzo, in contrast to an alleged emphasis on sherds that looked like possible imports in the Basin of Mexico and Oaxaca samples.

The misapprehension here has to do with the fact that the sampling design in the Olmec study, like many ceramic provenance studies, had two goals. One goal was to estimate the range of compositional variation in local ceramics for the various locations sampled. For Oaxaca, the Basin of Mexico, and Mazatán, the MURR database already included numerous raw material analyses as well as sherds representing multiple paste types and textures (e.g., Nichols et al. [2002] for the Basin of Mexico; Neff [2002] and Neff and Glascock [2002] for Mazatán; Herrera et al. [1999] and Neff and Glascock [2002] for Oaxaca). Flannery et al. (2005) must have known this, since, for example, Neff and Glascock (2002: 2 – 3, Figures 10 – 11, and Table 6), whom they cite, discuss the samples from the various regions and use the raw material analyses to generate maps indicating specific production zones for the Tlapacoya and local Mazatán groups.

Blomster et al.'s (2005:1069) discussion of the highland samples was necessarily abbreviated for publication in *Science*, but details were provided in the supplementary on-line documentation. In Oaxaca, the sample includes raw materials and pottery from modern pottery-making communities (Joyce et al. forthcoming). In addition, Blomster included approximately a dozen sherds from Etlatongo that either were undecorated or exhibit what appears to be local decoration (Blomster et al. 2005:Table S1). Blomster's sample also included undecorated sherds from the Valley of Oaxaca sites San José Mogote and Hacienda Blanca.

For San Lorenzo, the range of local ceramic compositional variation had yet to be evaluated, so the sample analyzed for the Olmec study included both local raw materials and a wide range of pastes that would permit reliable assessment of the range of ceramic compositions that could have been produced from local ceramic resources. There was no deliberate attempt to slant the San Lorenzo sample in favor of local materials, just as there was no effort to "[ignore] the drab utilitarian wares" at the highland sites (Flannery et al. 2005:11219). Instead, in all regions, the goal was to understand the full range of what constitutes "local," so that imports and exports could be identified reliably.

The second goal in the Olmec study was to evaluate to what extent Early Formative pottery, especially carved-incised and fine-white pottery, may have been transported among regions. Addressing this question, obviously, requires selective sampling of carved-incised and fine-white pottery. Flannery et al. (2005) suggest that this goal was not achieved at San Lorenzo, since, although a reasonable number of Xochiltepec White sherds were sampled (19), only five "Calzadas Carved" sherds from that site were analyzed (Blomster et al.2005: Table S1). In fact, however, the initial 50 samples submitted by Blomster (1998a) included no "drab" utilitarian wares from San Lorenzo, and many were actually included *because* they bore a superficial resemblance to

Oaxacan gray wares, and might have supported the model of Oaxacan export of pots to San Lorenzo (Blomster 1998a, 2004).

A careful evaluation of the San Lorenzo sample reported in Blomster et al. (2005:Table S2 and S3) shows that it contains considerably more than the five Calzadas Carved sherds mentioned by Flannery et al. (2005). The ongoing project directed by Ann Cyphers (1996, 1997, 1999) at San Lorenzo is changing aspects of the ceramic typology used at the site, with Calzadas Carved and Limón Incised (the other major decorated Olmec export ware) being subsumed under the type “Tigrillo” (Symonds et al. 2002: Appendix II). The new classification system was used in listing these carved/incised sherds in the ceramic type column in Tables S2 and S3, and little else was said about them in Blomster et al. (2005). There are, however, at least 11 additional Calzadas Carved sherds included in Blomster et al. (2005), all of which have a clear San Lorenzo origin as determined by INAA. In fact, 5 of these (SLN0376, SLN0377, SLN0420, SLN0438, and SLN0455) are explicitly listed as “Calzadas” in the “descrip/comments” column in Table S2, and in the “other description” column of Table S3 (Blomster et al. 2005). This more than triples the Calzadas Carved sample for a total of at least 16. Parenthetically, a sample of 69 sherds, many of them Calzadas Carved from Coe and Diehl’s (1980) excavations is presently being analyzed at MURR.

All samples are finite, and therefore none is perfect. However, the large sample analyzed in the Olmec study (nearly 1000 ceramics and 623 raw clays) is well designed to provide a reliable indication of whether and approximately how much carved-incised and fine-white pottery may have been transported inter-regionally in Early Formative Mesoamerica. In contrast, the petrographic sample of Stoltman et al. (2005:11216) consisted of approximately 20 (the authors never provide a precise sample size), of which "about half … had previously been singled out as possible trade pieces." As discussed in greater detail below, one can question provenance results based on such a small, carefully selected petrographic sample, and it certainly does not permit any assessment of the relative volume of interregional exchange.

Statistical Issues

Very early on in the course of developing archaeometric INAA, it became apparent that a rote approach to statistical analysis would produce misleading results. Somewhat akin to archaeological fieldwork, creation of reliable ceramic provenance data requires a multi-stage approach in which source-related groups are proposed, checked, and rechecked. Edward V. Sayre (1975) and Garman Harbottle (1976) recognized the special requirements of provenance studies and began tailoring pattern-recognition and group-evaluation techniques so that they would yield reliable source-related compositional groups, while minimizing the chances of erroneously detecting exports where there were none. The basic approach adopted by Sayre and Harbottle has been elaborated and refined (Bishop and Neff 1989; Glascock 1992; Neff 2002) and has been used successfully on numerous ceramic INAA projects at MURR and elsewhere (e.g., Glascock, ed. 2003; Glowacki and Neff, eds. 2002; Neff, ed., 1992). The Olmec INAA study is a textbook example of how this approach can yield clear, strong compositional patterns with unambiguous implications about interregional movement of goods. Conversely, the "re-analyses" of the MURR Olmec data by Stoltman et al. (2005) and Flannery et al. (2005) provide excellent illustrations of how far wrong one can go without fully understanding the underlying logic of the statistical technique and without considering whether the model implied by the technique is appropriate for data at hand and the questions at issue.

The basic goal in chemistry-based ceramic provenance determination is to delineate one or more source-related compositional groups. Such groups can be conceived as centers of mass in the multi-dimensional space defined by the full set of elemental concentrations (e.g., Harbottle 1976). Archaeological context provides one useful piece of information about which analyzed specimens might be expected to group together. Additional information useful in forming initial groups may come from typology (e.g., carved-incised vs fine white pottery in the present case) or from numerical pattern recognition (e.g., cluster analysis, principal components analysis, factor analysis, or simple bivariate elemental-concentration plots). In any case, however, the initial groups represent *hypotheses* about subgroup structure in the data that must be tested by further analysis. They are the beginning of quantitative data analysis, not the end (Neff 2002).

Sayre (1975) recognized that a generalization of the univariate z-score, known as Mahalanobis distance, could be used to test the make-up of compositional groups on a case-by-case basis. This metric evaluates how “close” a specimen lies to the centroid of the various groups being tested, given the correlational properties (“shapes”) of the different groups. One important refinement of Sayre’s basic approach is the “jackknife,” whereby specimens assigned to a particular group are removed from the group before calculating their own probabilities of membership. This is a conservative approach that eliminates the bias of the kind that would favor spurious support for preconceptions about group membership.

Use of Mahalanobis distances, especially with the jackknife, usually identifies a subset of specimens that are so distant from all group centroids that they cannot be confidently assigned to any group. These specimens may be statistical outliers from one of the defined groups, they may represent divergent paste preparation practices or diagenetic anomalies (discussed further in the next section), or they may pertain to sources sampled so sparsely that they were not recognized as distinct groups. Forcing marginal specimens into the group to which they lie closest does not make that specimen any less marginal, and it broadens the group into which it is forced, thus blurring the discrimination between groups. As a result, standard practice at most laboratories that carry out archaeometric INAA is to err on the side of minimizing erroneous assignments, leaving marginal specimens unassigned. Note, however, that information about which group is the best assignment for a given specimen is nonetheless preserved in the probabilities of group membership (e.g., Neff and Glascock 2002: Tables 3 - 5).

Specimens that do not fit the dominant typological characteristics of a compositional group are sometimes left unassigned as well. In the Olmec study, for instance, some non-white San Lorenzo sherds were left out of the San Lorenzo White group despite the fact that they exceeded 5% probability of membership in the group. As with the statistical outliers, this is a conservative approach that raises the bar for membership in a group while still preserving the information about which group is the best match for a given specimen given current data.

Stoltman et al. (2005) and Flannery et al. (2005) point to the unassigned specimens in the Olmec study as a reservoir of possibly highland produced and traded ceramics, suggesting specifically that Blomster et al. (2005) missed evidence in the

INAA data for highland imports to San Lorenzo. For instance, Stoltman et al. (2005:11215) state, “no fewer than 48 sherds from San Lorenzo (any one of which could have been foreign) were listed as unassigned.” In fact, all but 10 of the 48 sherds are best assigned to either the San Lorenzo or San Lorenzo White groups (Neff and Glascock 2002: Table 5). The effect of including these 38 unassigned specimens in the San Lorenzo groups (the best assignment statistically) would have been to *broaden* those groups, thereby also inflating the probabilities that unassigned specimens from other sites would be assigned to San Lorenzo. In other words, forcing unassigned specimens into the group to which they lie closest, as Stoltman et al. (2005) would appear to favor, would have further accentuated the role of San Lorenzo as an *exporter* of pottery. The default assumption was that the cost of exporting ceramics with only human transport would have made interregional movement of ceramics infrequent, so the bar was deliberately set high for inferring interregional movement. If anything, however, this approach *underestimates* the extent to which export of pottery from San Lorenzo was not balanced by a return flow of ceramics from other regions, a point made in Blomster et al. (2005:1070).

All 10 unassigned specimens from San Lorenzo that show a higher probability of membership in a group other than San Lorenzo are weakly linked to a small group (n = 41) from San Isidro, Chiapas. Mahalanobis distance-based probabilities for small groups are inflated to begin with, and even the highest probabilities in this case fall outside of the 98% probability boundary for San Isidro. An inference of export of San Isidro ceramics to San Lorenzo thus would have to be advanced on very slim statistical evidence. Readers who may still think that Blomster et al. (2005) disguised potential highland Mexican imports to San Lorenzo are invited to scan the long columns 0.000% probabilities listed under “Oaxaca” and “Tlapacoya” in Table 5 of the original technical report (Neff and Glascock 2002). The same table shows that Mazatán and Tehuantepec similarly stand out as exceedingly unlikely sources for any of the unassigned specimens from San Lorenzo.

To reiterate, with only human transport, the default assumption should be that any given pot is a local product, and the statistical bar for non-local status should be set high in order to minimize erroneous inferences of interregional exchange. In the Olmec study, Blomster et al. (2005) set the bar high for membership in *all* of the reference groups, and found that *only the San Lorenzo group included any specimens found at sites outside of the inferred source region for the group*. These specimens are unambiguously assignable to San Lorenzo; there is virtually no doubt that they were exported from Gulf lowland ceramic production centers during San Lorenzo’s heyday. In contrast, *not a single specimen* found at San Lorenzo can be assigned to any source other than San Lorenzo, and no conceivable lowering of the bar admits any of the unassigned San Lorenzo specimens to the Tlapacoya, Mazatán, Oaxaca, or Tehuantepec reference groups.

How are the above inferences about the lopsided nature of Early Formative ceramic exchange to be reconciled with statistical re-analyses of MURR data by Stoltman et al. (2005) and Flannery et al. (2005), which purportedly indicate multi-way movement of Early Formative ceramics? The answer is that misapplication of packaged statistical procedures and limited understanding of chemistry-based sourcing produced a result that was invalid, yet, it seems, compatible with the investigators’ preconceptions.

Stoltman et al. (2005) carried out a discriminant analysis in which the groups fed into the analysis were defined by archaeological context alone. As noted above, however, while archaeological context may be one good starting point for recognizing source-related groups, they are hypotheses to be tested, not the end of the analysis. In the Olmec study, the groups defined purely by archaeological context include a variety of suspected local and imported pottery. This is an artifact of the sampling design used in the INAA study (Blomster et al. 2005; Neff and Glascock 2002), the purpose of which was to evaluate the extent to which Early Formative ceramics may have been moved between regions.

The fallacy of Stoltman et al.'s (2005) statistical approach is exemplified by the conclusions drawn about Etlatongo, in the Mixteca Alta of Oaxaca. Stoltman et al. (2005: Tables 1 and 2) find, based on their discriminant analysis, that somewhere around 50% of Etlatongo products were exported to other sites, and they speculate that this result reflects either sampling bias or the importance of the Etlatongo region's claimed or "known" kaolinite sources.[3] Any familiarity of the *PNAS* authors with Etlatongo ceramics should have raised a red flag about the implausibility of this interpretation. At Etlatongo, Blomster selected sherds that appeared to represent several different types of locally made "café paste" (coarse and fine varieties), as well as possible imported ceramics, including carved-incised and fine-white pottery. Indeed, the results of the INAA discriminated at least two types of local café pastes, which match the visual inspection of these ceramics (Blomster 1998a; 2004), together with two groups of imports, fine white and carved-incised. Stoltman et al. (2005) combine these four visually and compositionally distinct groups into a single "local Etlatongo group." This heterogeneous amalgam subsumes so much compositional variation that a very broad range of analyzed pottery will now appear to qualify as "local Etlatongo" products.

The effect of lumping all sherds from Etlatongo into a single group is illustrated in Figures 6 and 7. The structure Neff and Glascock (2002) identified in the Etlatongo data, indicated by the smaller ellipses, comprises four groups, two found only at Etlatongo and two consisting of imports from the Gulf lowlands. The groups are clearly distinct on numerous projections of the data, including the two largest dimensions of variance (Figure 6). When the data are all lumped into a single group, as Stoltman et al. (2005) did for their discriminant analysis, the range of variation of this “group” is magnified tremendously on all dimensions; iron, for instance (Figure 7) now varies over almost an order of magnitude.

In a discriminant analysis, a highly variable group defined only by context of discovery that actually subsumes several compositionally distinct groups has a clear advantage in terms of how many of the cases will appear to be assignable to it. That is, when one assumes that everything *found* at site A was *made* at site A, the probability hyper-ellipsoid for site A is enlarged dramatically, to the point that sherds from sites B, C, etc. will begin to fall within it, even if they were not made at site A. More generally, by using only one criterion (context of discovery) to form groups, all hyper-ellipsoids are enlarged, and the overall ability to discriminate sources is degraded.

By creating a heterogeneous “Etlatongo group” that combined at least four distinct groups, Stoltman et al. (2005) forced their analysis to show that Etlatongo potters exported more pottery than was consumed locally, a peculiar conclusion that they then had to explain by reference to biased sampling or Etlatongo’s desirable kaolinite clay sources. In fact, however, in the INAA sample (which deliberately included likely imports) there is *not a single pot* that was exported from Etlatongo. Instead, the Etlatongo sample consists largely of *imported pots* made at production centers at or near the Gulf lowland Olmec center of San Lorenzo.

Apparent “exports” from other sites identified by Stoltman et al. (2005 Tables 1 and 2) are due to similar though less extreme effects of increased group heterogeneity. The only region that did not export pottery according to the Stoltman et al. (2005) analysis, Mazatán, is so distinct in composition (chromium concentrations about 1/10th of compositions found farther north in Mexico) that the local, low-chromium signature overwhelms the increased heterogeneity due to inclusion of non-local (San Lorenzo) specimens in the group.

Flannery et al. (2005) present a different reanalysis of the MURR data in which 184 “gray ware” sherds from Tlapacoya, Etlatongo, Oaxaca, and San Lorenzo are subjected to a factor analysis. Factor analysis is a useful pattern-recognition technique that reduces the dimensionality of multivariate data and facilitates the recognition of potential subgroups, much like principal components analysis. As discussed previously, however, recognition of potential subgroups in the compositional data is the beginning rather than the end of the analysis. Flannery et al. (2005) discuss a projection of the data onto Factors 1 and 2, offering a highly impressionistic interpretation of what they accurately characterize as a “shotgun blast.” Plots of this kind are used routinely during the very first stages of data analysis, when a broad understanding of possible subgroup structure is sought. For at least 35 years, however, users of INAA have recognized that an initial exploration of subgroup structure is very far from the end of the story. It is naive indeed for Flannery and colleagues to claim that their impressionistic interpretation of a single two-dimensional factor-analysis plot represents a more valid understanding of structure in the Olmec data than that produced via painstaking, iterative application of pattern recognition and multivariate group refinement.

Additional Methodological Misapprehensions

Stoltman et al. (2005) and Flannery et al. (2005) repeat an old assertion about INAA being invalid for pottery because pots are not rocks but “human artifacts.” In the critiques of the Olmec study, this assertion helps create a cloud of confusion within which the superiority of petrography can be asserted without demonstration. Insistence on the absolute superiority of either petrography or chemistry is misguided, since sometimes superior geographic resolution can be achieved with bulk elemental analysis and other times superior resolution is possible with petrography. Equally important, the fact that the two techniques usefully complement each other (Bishop and Rands 1980; Bishop et al. 1982; Montana et al. 2003; Rands and Bishop 1980) is lost in an argument about the superiority of one over the other.

The basic complaint about INAA and other bulk chemical techniques is that they yield a chemical profile that, in the words of Stoltman et al. (2005: 11214), “derive[s] from at least five sources: (i) the clay, (ii) any added aplastics (temper), (iii) the water used to moisten the clay, which may contain such soluble elements as sodium, potassium, calcium, magnesium, or iron, (iv) any substance stored, cooked, or transported in the pot, and (v) diagenesis, the absorption of chemicals from the soil in which the sherds have lain buried for millennia.” All of these effects have been recognized and discussed by proponents of chemistry-based sourcing, beginning with the very earliest applications of INAA to ceramic source determination (Sayre and Dodson 1957; also see Bishop et al. 1982 and Neff et al. 2001), but they are raised in this context as if users of INAA habitually overlook them. These effects have also been examined in ethnographic contexts, where technology is known and the relationship between paste preparation and bulk elemental profiles can be evaluated directly (Arnold et al. 1991, 1999, 2000).

In principle, technology, use, and diagenesis might affect patterning in bulk elemental data in two distinct ways. One possible effect is to *create* compositional differences where none existed between the raw clay sources. This appears to be what Flannery et al. (2005: 11220-11221) have in mind when they assert that "[o]ne cannot rule out the possibility that some of the most critical elements entered the sherds later, through diagenesis." In most INAA studies (including those undertaken at MURR) investigators implicitly or explicitly evaluate multiple working hypotheses about identified subgroups (Neff et al. 2003). If, for example, elevated calcium and strontium (two of the soluble elements Flannery et al. [2005] worry about) are discriminators of one group from another, viable *a priori* hypotheses about this data structure would include: (1) the groups represent clay-source differences; (2) the groups are produced by tempering, e.g., addition of limestone or shell temper; (3) the group with elevated calcium and strontium reflects use of some of the vessels for preparing corn meal (a scenario suggested by Stoltman et al. 2005:11214), or (4) the groups represent some combination of all of these effects.

Multiple hypotheses about structure in bulk ceramic compositional data can be evaluated by several means (e.g., Bishop et al. 1982; Kosakowsky et al. 1999; Neff et al. 1999; Neff et al. 2003; Neff and Sheets 2005; Rautman et al. 1999), including electron microprobe, laser ablation-ICP-mass spectrometry, and petrographic analysis (hence the complementary relationship of petrography and chemistry mentioned above). Although extended discussion of these methods is beyond the scope of the present paper (but see below for a discussion of petrographic analysis), one principle is relevant in light of Flannery et al.'s (2005) contention that diagenesis may be creating patterning in the Olmec data: if ceramic compositional groups can be linked directly to sampled raw materials, such a finding favors rejection of both ancient use practices and diagenesis as causes of group discrimination. In the case of the Olmec study, the ceramic groups attributed to San Lorenzo, Mazatán, Oaxaca, and Tlapacoya are all linked directly to geographic source locations by the fact that raw material samples from those locations fall within the range of variation of the ceramic reference groups. Thus, any post-manufacture effect on the compositional profiles of Olmec sherds is insufficient to obscure the relation of the ceramics to source raw materials.

Two other considerations further strengthen the inference that regional Olmec reference groups reflect raw-material differences. First, the groups are discriminated by many elements, including transition metals, rare-earth elements, and other immobile elements, and no stretch of the imagination could concoct a series of use or diagenetic effects that would create such profound compositional differences. Second, the mere fact that multiple compositional groups are found in multiple archaeological contexts (i.e., the local groups together with the San Lorenzo and San Lorenzo White groups) is inconsistent with Flannery et al.'s (2005) suggestion that differential diagenesis (a local effect of the burial environment) is responsible for the structure in the Olmec ceramic data.

The other possible effect of technology, use, and diagenesis is to increase the compositional variation of ceramics to the extent that differences between clay sources are obscured. Although experiments by Neff et al. (1988, 1989) have shown that the probability of such an effect is much smaller than intuition might suggest, the conservative approach to group assignment discussed in the previous section in any case guards against erroneous assignments when groups overlap at their edges. In the case of the reference groups defined in the Olmec study, the elemental differences are large and multivariate (see illustrations in Neff and Glascock 2002 and Blomster et al. 2005), so no matter how much broadening of the groups might have occurred due to technology, use, or diagenesis, such effects clearly have not obscured the interregional differences.

The fact that bulk ceramic compositional profiles reflect technology, use, and diagenesis as well as clay source differences should not be overlooked, and in fact *is not* overlooked in INAA studies. Such effects may attenuate geographical resolution and play a role in creating statistical outliers (some of the “unassigned” specimens) in the Olmec study. Further, the natural environment also imposes limits on geographical resolution. No measuring instrument is infinitely precise, and scientific rigor demands that the limitations of one’s measuring instruments be assessed carefully and comprehensively. This dictum applies as much to petrographic analysis as it does to chemical analysis, a point to which we return below.

Recognition of the need to assess the limits that the natural environment imposes on geographical resolution of INAA prompted discussion of the surprising similarity of some Late Formative Oaxacan gray ware (Gris-1) to compositions characteristic of the San Lorenzo region (Neff and Glascock 2002). Stoltman et al. (2005) and Flannery et al. (2005) seize on this discussion as an Achilles Heel in the Olmec study, Stoltman et al. (2005:11214) stating, for instance, “[n]owhere are the limitations of INAA more evident than in Neff and Glascock's … acknowledgment [of the overlap of Oaxacan Late Formative and San Lorenzo compositions]."

To repeat, we believe that careful assessment of the precision of one's measuring instruments is part of good science. However, since Stoltman et al. (2005) and Flannery et al. (2005) insinuate that this discussion exposes a fatal flaw in the Olmec study, some significant details not mentioned by them deserve reiteration. First, although there is surprising overlap of the Late Formative Oaxaca Gris-1 and San Lorenzo groups on many projections of the data, there is, in fact, a clear *multivariate* separation, which can be illustrated by a canonical discriminant analysis (Figure 8). Second, the attenuation of geographical resolution involves *only Late Formative Oaxacan gray wares*: as shown in Figure 8, the major axis of discrimination derived from the canonical discriminant analysis unambiguously separates Early Formative Oaxacan gray pottery from San Lorenzo. The unambiguous discrimination of San Lorenzo from Early Formative Oaxaca was demonstrated previously by the comparison of the two groups using Mahalanobis distances (Neff and Glascock 2002: Table 2). The important point here is that the chance that Early Formative ceramics included in our San Lorenzo group were actually made in Oaxaca is much more remote than might be suggested by the surprising similarity of Late Formative gray pottery to San Lorenzo compositions.

Publication of Raw Data

Stoltman et al. (2005) and Flannery et al. (2005) also imply that there is something suspicious about Blomster et al.'s (2005) use of the Late Formative Oaxacan gray ware reference collection. For instance, Stoltman et al. (2005:11215) complain that "[a]lso mentioned is a 'reference collection,' but no details, counts, or chemical elements for this collection are given." In other words, although Blomster et al. (2005) published over 1000 raw data generated by the Olmec project, they are faulted for failure to publish the Late Formative data (which were generated in separate projects whose results were still being analyzed [Joyce et al. forthcoming]). MURR's record of publishing raw data (over 5000 raw INAA data publicly available at http://www.missouri.edu/~reahn/) speaks for itself on this issue and sets a standard for documentation met by few if any other archaeometry labs. In comparison, Stoltman et al. (2005) show a total of 10 photomicrographs and never specify their exact sample size.

The Stoltman et al. Petrographic Study

The fact that Stoltman's petrographic study yielded results apparently at odds with the results of INAA of nearly 1000 ceramics and several hundred raw material samples deserves further exploration. Even a large sample such as the Blomster et al. (2005) Olmec sample may miss low-frequency compositional groups. It is possible, for instance, that Stoltman et al. (2005) are correct in their identification of several "Leandro Gray" sherds found at San Lorenzo as Oaxacan imports. While gray sherds were included in the San Lorenzo collection analyzed by INAA, "Leandro Gray" was a type created for Oaxaca Valley pottery (Flannery and Marcus 1994), and the category was not used in the sorting of San Lorenzo collections sampled for the INAA study. The San Lorenzo sherds meeting the criteria for this type analyzed by Stoltman et al. (2005) have not yet been made available for analysis.[4] Glascock's offer to analyze Stoltman's samples at MURR expense is an expression of our desire to explore this possibility further. The majority of Leandro Gray specimens analyzed from Oaxaca were assigned to the Oaxaca reference group by INAA (Neff and Glascock 2002: Table 1), so we would not be too surprised if examples identified as the same type from the Gulf lowlands proved to be Oaxaca imports. Such a finding would not change the lopsided ceramic circulation pattern for fine white vessels or those with Olmec-style motifs revealed by our INAA results, however.

At the moment, the absence of a secure intersection between the INAA and petrographic samples precludes definitive analysis of the reasons for the contradictory findings. If INAA and petrography were to yield contradictory results for the *same* sherds, we would argue that neither result deserves to be dismissed automatically, as Stoltman et al. (2005) seem to advocate. INAA and petrography are both instruments for monitoring source location, and both have inherent limitations on their resolution. We have already discussed the natural and technological effects that limit the resolution achievable with bulk elemental approaches to ceramic source determination. We turn now to a brief consideration of the methods of petrography-based ceramic provenance research and of limitations in the research design of Stoltman et al. (2005).

The principle underlying both the bulk-chemical approach and the petrographic approach to ceramic source determination is called the “provenance postulate” (Weigand et al. 1977). The provenance postulate specifies that between-source differences must exceed within-source variation in order for source-discrimination to be possible. The raw measurements may be either elemental or mineralogical, and in either case variability may be assessed in either qualitative or quantitative terms (Neff 2000). The Olmec INAA project employed quantitative elemental measurements, whereas Stoltman et al.’s (2005) petrographic study employed qualitative mineralogical measurements. Even if one accepts Stoltman et al.’s (2005) assertion that petrographic data are inherently superior for ceramic provenance determination, any petrography-based attribution of provenance still depends on characterizing both the range of petrographic variation within regions (qualitative variation in this case) and the differences between regions.

The methods used to assess intra- and inter-regional elemental variation in ceramics are discussed in previous sections and need not be repeated here. Secure attribution of provenance in petrographic studies demands similarly explicit consideration of the range of mineralogical variation within and between regions, including, ideally, sampling and analysis of raw materials. The petrography-based ceramic provenance research of Heidke, Miksa, and their collaborators in the Southwest, for instance, relies on extensive sampling of sands in order to develop petrofacies models of the distributions of sand compositions within drainage basins (e.g., Heidke et al. 2002).

The identification by Stoltman et al. (2005) of highland imports at San Lorenzo directly contradicts the findings of the INAA study and constitutes a crucial piece of their argument for multi-way movement of Early Formative ceramics. From a methodological perspective, it would therefore seem critically important to characterize the range of qualitative petrographic variation expected in San Lorenzo area ceramics, so that ceramics falling outside that range (imports) could be unambiguously identified. Stoltman et al. (2005:11216) analyzed a single presumed local San Lorenzo ceramic (Perdida Black-and-White) specimen, which turned out to be tempered with fine calcareous sand. They do not specify from which project – and from what context – this sample originated, nor why they believe it to be local (Stoltman et al. 2005:11216). They did not sample raw materials, (in contrast to the INAA study, which included 123 raw clay samples from the vicinity of San Lorenzo). Stoltman et al. (2005) are therefore incautious to claim that their lone thin section from San Lorenzo provides a basis for identifying imports to the Gulf lowlands.

San Lorenzo is surrounded by Quaternary alluvium that derives from Tertiary and Mesozoic limestones as well as recent volcanic rocks of the Tuxtlas Mountains. In addition, the Río Coatzacoalcos drains across much older metamorphic rocks. For Stoltman et al. (2005) to assert, based on a single thin section of a *presumed* local ceramic sample, that San Lorenzo ceramics are characterized by only one kind of tempering material (calcareous sand) is unwarranted. Volcanic glass shards would be expectable in alluvium derived partially from the Tuxtlas Mountains, and alluvium of the Río Coatzacoalcos might be expected to contain weathering products from a variety of rocks, including Paleozoic metamorphics. Stoltman et al. themselves mention at least one other class of San Lorenzo area temper, "quartzitic sand," or "fine quartz sand," identified in an earlier study by Payne and considered a marker of Xochiltepec White produced in the San Lorenzo area (Stoltman et al. 2005:11213 and 11217).[5]

Stoltman et al. (2005) analyzed more than one presumed-local thin section from Oaxaca, but they inadequately assess the range of mineralogical variation likely to be found in Oaxaca Valley ceramics. The seven thin sections from presumed-local sherds were restricted to a single paste type characteristic of Early Formative gray ware made in the northern arm of the valley, in the vicinity of Monte Alban and San José Mogote. These seven thin sections all had gneiss-derived grit temper plus volcanic glass shards inferred to be natural inclusions in the clay. The gneiss is associated with metamorphic rocks at the edges of the Oaxaca alluvium, while the glass shards presumably are derived from Miocene volcanics. As Payne (1994) has documented, however, ceramic raw materials in the Oaxaca Valley also include sedimentary clays derived from weathering of a variety of rocks that surround the valley, notably including Mezozoic limestones. At one time, Flannery and Marcus themselves recognized the importance of characterizing the range of mineralogical variation in the Oaxaca Valley, as indicated by their statement that, “not all Delfina Fine Gray vessels were made from the same clay body, since different parts of the valley [of Oaxaca] had different parent geological materials” (Flannery and Marcus 1994:262). Because Stoltman et al. (2005) did not document how the different geological environments of the valley are expressed in ceramic thin sections they have provided an inadequate basis for petrographic identification of Oaxaca exports to other regions, such as the Gulf lowlands.

The importance of establishing reliable baseline information about the range of natural and added non-plastics that might be found in pottery from the various potential source regions is highlighted by one additional example. Two Delfina Fine Gray sherds from San José Mogote and one Calzadas Carved sherd from San Lorenzo were found by Stoltman et al. (2005) to have very similar pastes characterized by fine-grained polycrystalline quartz. While Stoltman et al. (2005:11216) suggest that the three sherds derive from an unknown highland source, neither Oaxaca nor San Lorenzo can be ruled out as potential sources because the range of mineralogical variation in these regions has not been characterized. Fine-grained quartz is a common-enough constituent of alluvial sediments that it might be consistent with either region. The INAA study placed most sherds identified as Delfina Fine Gray and Calzadas Carved in the San Lorenzo reference group (Blomster et al. 2005: Table S3; Neff and Glascock 2002: Table 1), so it is most likely that these three fine-grained quartz-tempered sherds are not from an unknown highland source but rather from the vicinity of San Lorenzo. “Fine quartzite sand” has been an accepted marker of San Lorenzo Calzadas Carved for some time (Coe and Diehl’s 1980:16; Flannery and Marcus 1994:263; 2000:28), and, as noted above, Stoltman et al. (2005:11213, 11217) mention “quartzitic sand” and “fine quartz sand” as diagnostic of San Lorenzo.

The fact that fine-grained quartz is so common in sediments renders its value as an indicator of source highly questionable.[6] Delfina Fine Gray and Calzadas Carved therefore may be an instance in which the geographic resolution of petrography-based ceramic provenance determination is very coarse in comparison to INAA, which unambiguously assigns most examples of these types to San Lorenzo (Blomster et al. 2005: Table S3). As noted before, however, an absolute insistence on the superiority of *either* petrography or chemistry is misguided; petrographic studies pursued with adequate geologic and archaeological sampling would certainly advance our understanding of Early Formative ceramic circulation, particularly if pursued in a collaborative framework that also included bulk elemental analysis.

Belief in the absolute superiority of petrography leads Stoltman et al. (2005:11214) to the assertion that results of petrography can “overturn” results of INAA. Their case in point is a study of pottery from Pinson Mounds, Tennessee. In the Pinson Mounds study, Stoltman and Mainfort (2002) purport to show that sherds believed on stylistic grounds to be imports but identified as local by INAA (Mainfort et al. 1997) are in fact imports (thus “overturning” the INAA study). The 11 stylistically non-local sherds were all sand-tempered (Stoltman and Mainfort 2002: Table 3), like local Pinson pottery. However, Stoltman and Mainfort used point counts to measure the relative proportions of sand, silt, and matrix, and identified as non-local anything with a texture statistically different from most Pinson pottery (i.e., more than two standard deviations above or below the silt, sand, or matrix mean). A total of three of the 11 potential imports showed statistically aberrant textures, which would seem slim evidence on which to base an inference of importation from as far away as southwestern Georgia. Stoltman and Mainfort, however, ask archaeologists to believe that characterization of ceramic paste texture is more sensitive to provenance differences than quantitative measurement of 33 major, minor, and trace elements by INAA. Because their claim seemed feeble, Neff, Glascock, and their colleagues chose not to publish a response to the Pinson petrographic study. The claim still seems weak, as does the claim that the petrographic study of a handful of Early Formative sherds "overturns" the results of the INAA study of nearly 1000 ceramics and hundreds of raw clays.

The "Mother Culture" Debate

Blomster et al. (2005) mentioned the "mother culture" vs "sister culture" debate as part of the background on the intellectual history of Olmec studies, but they argued (p. 1068) for moving beyond the mother vs sister dichotomy. They noted that mother culture advocates have discussed "the dissemination of the social, political, and religious institutions of the Olmec" but they did not argue that their data proved this view to the exclusion of all others. Instead, they discussed pottery compositional data and what they showed about the circulation of vessels with Olmec-style motifs. They also took note of local facsimiles of these designs at Etlatongo and the role of local producers. The authors of the present article vary greatly in their opinions on how much influence the Olmec had on their contemporaries, despite unanimous agreement that the results of the Olmec INAA study were misrepresented by Stoltman et al. (2005) and Flannery et al. (2005).

Nor did Blomster et al. (2005) attempt any sweeping conclusions about the role of exchange in Early Formative cultural evolution. Flannery et al. (2005) exaggerate their views by imputing to them the belief that movement of vessels denies the possibility of complex innovations elsewhere and complex inter-regional relationships. Explicit avowal of the "complex nature" of Olmec relationships with their neighbors (Blomster et al 2005.: 1068) and the "multifaceted" interaction of producers and consumers of Olmec-style pottery (Blomster et al. 2005:1071) contradicts such exaggerations.

Flannery et al. (2005:11221) ridicule Blomster et al.'s (2005) conclusion that ceramics tended to flow out of the Gulf lowlands but not back in, contending that "unreciprocated trade among societies of this type is not typical or even viable." Flannery et al.'s (2005) discussion of "unreciprocated trade" pivots on the false claim that Blomster et al. (2005) suggest that *nothing* moved into the Gulf lowlands in exchange for the exported carved-incised and fine white pottery. Blomster et al. (2005) made no such suggestion. In an article focused on compositional analysis and exchange of vessels with Olmec-style motifs, Blomster et al. (2005) did not even write about Early Formative trade in general. Still, there is the valid question of what, in fact, flowed from highland zones to the Gulf lowlands.

Since exchange makes most sense if both parties gain, it may be expected to involve an exchange of goods that are relatively cheap locally for imported goods that are relatively dear. From this perspective, it is Flannery et al.'s (2005) insistence on reciprocal exchange of *ceramics* that could be construed as a non-viable argument.

Ceramics may be exchanged, of course, if, say, different communities specialize in distinct fine ware classes. Or, as Flannery et al. (2005) suggest, it is possible that it was the contents rather than the ceramics themselves that were exchanged, although in the Olmec case it seems unlikely that heavy, fragile, and bulky carved-incised serving bowls were used as containers for long-distance transport of “desired products” between Early Formative centers (Flannery et al. 2005:11221). In any case, in light of the demonstrated lopsidedness of Early Formative ceramic circulation, perhaps the most viable suggestion is that Gulf lowland pottery was exchanged for goods that were either unavailable or relatively expensive in the Gulf lowlands. Thus, for instance, highland centers near obsidian sources, such as Tlapacoya, might have provided obsidian in exchange for the carved-incised pottery of Gulf lowland origin; Clark (1997:218) enumerates other possible imports to the Gulf lowlands, and Flannery (1968) has done so in the past as well.

Finally, Flannery et al. (2005) summarize their position as one that is scientifically defensible and in opposition to the Blomster et al. (2005) arguments, which they label “creationist.” Political arguments often make use of tendentious phrasing in order to make opposing views seem indefensible. Linguist George Lakoff (2004) calls this style of argument “framing.” Framing consists of using words and phrases that invoke images that a proponent feels will resonate with the reader. These images may, in fact, represent the opposite of what is actually being stated. Like other social sciences, archaeology is not immune to arguments by “framing,” and over the years the literature has become filled with examples. Flannery et al.’s (2005) contention that Blomster et al. (2005) view “Mesoamerican civilization as the product of a kind of intelligent design” is an argument by framing. As we point out earlier in this section, there are good models that are consistent with the finding that San Lorenzo was predominantly a donor rather than a recipient of ceramics decorated in the Olmec style.

Conclusion

The objective of the analyses of Neff and Glascock (2002) and Blomster et al. (2005) was to build from primary data on individual sherd bulk elemental concentrations to reliable derived data consisting of compositional reference groups and associated information on inter-regional transport of particular vessels. It is the *creation of reliable data* that is at stake. Archaeologists and other scientists use derived data routinely, although derived data are not often viewed as such in archaeology. In the same way that poor practices in excavation or survey can create unreliable data, poor methods in ceramic provenance research can build unreliable data. Good methods (the basis for creation of reliable data) incorporate rigorous assessment of limitations on the resolution of one's measuring instruments. The measuring instrument used by Blomster et al. (2005), INAA, has limitations, and these limitations were evaluated and discussed explicitly (esp. Neff and Glascock 2002). Despite its limitations, this measuring instrument produced an exceptionally clear result that demonstrated a marked lopsidedness in the interregional transport of Early Formative carved-incised and white pottery. Since the pattern emerged from analysis of a large sample, and pains were taken to minimize erroneous detection of interregional transport, this pattern would seem to qualify as reliable data. Inasmuch as some past discussions have advanced complex interregional interpretations on the basis of very modest evidence, the clear patterning detected in such a large INAA data set would seem to represent progress in Olmec archaeology.

Flannery et al. (2005) and Stoltman et al. (2005) found the results of the Olmec INAA study unpalatable and sought means to "overturn" the results. However, their statistical re-analyses commit exactly the kinds of errors that motivated a highly conservative approach in the original Blomster et al. (2005) study. The resulting *unreliable* data produced by misapplication of statistical analysis not surprisingly support the preconceived view that "pottery moved freely among sites like Tlapacoya, San José Mogote, and San Lorenzo" (Stoltman et al. 2005:11213). As noted above, an exchange system in which the participants do not specialize but rather all make and exchange the same goods (pottery) does not seem viable economically, unless distinct classes of fine pottery were exchanged; more importantly, it is manifestly contradicted by a more careful statistical analysis of the INAA data (Blomster et al. 2005; Neff and Glascock 2002).

The Stoltman et al. (2005) petrographic study has methodological weaknesses, as discussed above, but results obtained with a technique that has repeatedly demonstrated its value to archaeology for over 70 years should not be dismissed out of hand. In particular, considering that INAA of Leandro Gray sherds from Oaxaca showed them to be predominantly Oaxacan in origin, it would be no surprise if future INAA of "Leandro Gray" sherds from San Lorenzo were to confirm at least some of them to be Oaxacan imports. As noted previously, even large samples may miss low-frequency compositional groups, and, unfortunately, we cannot be certain that any of the gray sherds from San Lorenzo are the same "Leandro Gray" sherds analyzed by Stoltman (but see footnote 3). Finding a few Leandro Gray Oaxacan imports to San Lorenzo would, like the previous

INAA results, be important data to be considered in future discussions of the Olmec. But to claim that petrographic identification of a small number of imports “overturns” a pattern established by INAA of nearly 1000 Early Formative ceramics and hundreds of clays is a rash exaggeration at best.

Intra- and inter-regional interaction patterns were increasing in complexity and variability during the Early Formative period. The mother-sister culture debate is an element of Mesoamerican archaeology’s intellectual history that no longer serves scholars well in characterizing the complexity of information and material exchange patterns that existed during this period. To reiterate what Blomster et al. (2005:1068) stated "we endeavor to move beyond this dichotomy." The INAA findings offer new information about the movement of certain vessels from the San Lorenzo area and about the scale of inter-regional pottery transport among several other areas. Analyses in process at MURR (Cheetham, personal communications 2005) appear to provide further confirmation of the patterning identified in the earlier study. Compositional analyses of pottery using multiple approaches in combination with other work published or underway on lithics, figurines, and other artifacts will establish a solid base of information about intra- and inter-regional exchanges. Detailed stylistic studies will also contribute to better understanding of how information and goods circulated at different geographical scales.

Our purpose in this response is not to provide a synthesis of Early Formative Mesoamerican exchange relationships, but we believe that understanding of those relationships should be informed by the evidence that people at San Lorenzo made and exported vessels with Olmec-style symbols in modest but detectable quantities at a time when, to date, we lack evidence that people in other regions did so. We do not conclude from this observation that *no* pottery was ever transported by people who were moving among other regions. Moreover, other valuable objects that originated in non-Gulf areas were transported inter-regionally too. While the evidence persuades us that San Lorenzo and its support area were involved in production and exchange of ceramic prestige items that reached a number of regions, no one of us would suggest that regional variation across Mesoamerica in patterns of economic interaction should be ignored. To understand the bigger picture, it is counterproductive to polarize research advances in terms of mother-sister culture positions, which have led to entrenchment of views and commitment to political rather than scholarly agendas. In sum, Blomster et al. (2005) did not attempt any sweeping conclusions about Early Formative exchange. They, like Neff and Glascock (2002), stuck to the specifics of what the ceramic INAA data showed about circulation of carved-incised and fine white ceramics. The new information produced by the project deserves to be taken seriously.

Appendix: Hollow Babies and the Olmec Style

One of the thin sections analyzed by Stoltman et al. (2005:11217) comes from a white-slipped "baby doll," what or archaeologists call hollow babies (Blomster 1998b). Although Marcus (1998) has recently published a catalogue of Formative figurines from the Valley of Oaxaca, apparently the object they tested, from Feature 65 at San José Mogote, was not included in that study. The petrographic analysis is claimed as further support for the long-held belief by Flannery and Marcus (1994) that ceramic hollow babies, with Olmec-style physiognomies, originate in Central Mexico rather than the Gulf lowlands.

When Blomster (1998b) discovered a hollow baby at Etlatongo, he examined the literature on relatively intact hollow figurines, and discovered two things. First, much of what are called Olmec-style hollow babies do not conform to a robust definition of Olmec style (Coe 1965; Grove 1989); instead, approximately 20 intact hollow babies exist, while another group of hollow figurines includes a great variety of regional approximations (Blomster 2002: Tables 1 and 2). Second, the intact hollow babies from sites such as Tlatilco and Tlapacoya are all looted, without firm provenience. When hollow baby fragments recovered archaeologically are examined, it becomes clear that San Lorenzo yields a higher frequency of these objects than the Central Highlands (Blomster 2002:Table 3), although recent research in the Soconusco region of Chiapas also shows high frequencies at Cantón Corralito (Cheetham 2005).

An examination of the hollow figurines included in Marcus' study (1998) reveals that none can be considered hollow babies following a robust definition of the Olmec style (Blomster 2002). Most likely, the hollow figurine fragment comes from what Blomster (2002:181) refers to as "Group 2" hollow figurines. By not describing carefully what this "baby doll" looks like, but implying that it is an Olmec-style object made in Oaxaca, the *PNAS* authors commit the same kind of uncritical use of the Olmec-style concept that Grove (1989:9) correctly notes has led to its dilution.

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Endnotes

[1]One reviewer suggested that this paper should be authored only by the three original authors of the *Science* article, implying that the other authors did not contribute

sufficiently to merit co-authorship status. In fact, however, the individuals listed as co-authors all made major contributions to the substance and tone of the draft submitted to *Latin American Antiquity* through a long and interactive series of internet discussions of multiple earlier drafts. Their contributions are far more substantial than what is implied by a simple acknowledgment.

[2]In the interest of setting the record as straight as possible, it is worthwhile to note here that, although Flannery et al. (2005:11219) name Blomster as the individual responsible for sampling San Lorenzo, the Basin of Mexico, and Oaxaca collections, in fact the bulk of these samples were selected by a former University of Missouri-Columbia grad student, R. Sergio Herrera, as has been made clear in all associated publications (Blomster 1998a; Herrera et al. 1999; Neff and Glascock 2002: 2- 3). Regrettably, Herrera abandoned the project around 2001, but this should not diminish the importance of the work he carried out selecting a sample that laid the groundwork for the first large-scale evaluation of Early Formative interregional ceramic exchange.

[3]Neither Winter nor Blomster, who have worked in the Etlatongo region, are familiar with the kaolinite clay sources to which Stoltman et al. (2005) refer. Payne identified the most iron-free source of kaolin in Oaxaca in the Nochixtlán Valley (Flannery and Marcus 1994:205). While the source has not been well documented, Joyce Marcus (1994, personal communication) asserts that potters in Oaxaca circa 1970 used white kaolin from Nochixtlán. Local potters in Nochixtlán do not appear to exploit this source today, although it may have served in the past as a source for white slips and clays that imitated Xochiltepec White pottery (Blomster 1998a).

[4] There may, in fact, be some intersection of the petrographic and INAA samples. Although Flannery and Marcus (1994) did not identify the San Lorenzo sherds from which Pyne took samples originally identified as Oaxaca imports, Blomster searched specifically for them, and believes that he included three (BLM045, BLM050, and BLM053) in the current analysis (Blomster et al. 2005:Table S1). These were identified as possible Pyne-Flannery sherds because of their superficial resemblance to Leandro Gray, their context number, and the clear evidence of the recent removal of a fragment.

Sample BLM050 may be the sample referred to by Stoltman et al. (2005:11217) as TE-R-72-G (this assumes that the sherd is actually TE-R-2/G -- there is no 72 in the San Lorenzo numbering sequence); this sample comes from the 1966 Tenochtitlán Remolino excavations. Sample BLM045 may be Pyne-Flannery sample SL-RNW-St-1p@ (in which case the correct San Lorenzo number is SL-PNW-St-1pA), which comes from San Lorenzo's northwest ridge. Stoltman et al. (2005:11217) identify BLM050 and BLM045 as "clearly" Leandro Grays from Oaxaca. The additional Pyne-Flannery sherd, SL-B4-9-SUR (possibly sample BLM053 in Blomster et al.2005) was used up by Payne, who identified it as similar to Delfina Fine Gray, and proposed that it originated from alluvial clay like that used in the Valley of Oaxaca (Flannery and Marcus 1994:263). The INAA unambiguously assigns BLM045, BLM050, and BLM053 to the San Lorenzo local group (Blomster et al. 2005: Tables S1-S3).

Because of the problems detailed above regarding the collection of the Pyne-Flannery samples, it is important that whatever may remain of these sherds be returned to Coe so that they can be matched with the parent sherds in the Peabody Museum and so that additional analyses intended to resolve the possible discrepancy between the petrographic and INAA results can be carried out.

[5]The possibility that temper might be imported to San Lorenzo from a distant location conceivably could further augment petrographic variation in local ceramic pastes. Admittedly, such a possibility seems unlikely based on ethnographic observations (Arnold 1985). Nonetheless, long-distance movement of tempering materials cannot automatically be assumed away, as the long-mysterious case of volcanic ash in lowland Maya pottery (Shepard 1937) may illustrate.

[6]Indeed, in thousands of sherds examined visually and microscopically from Etlatongo, many local ceramics primarily contain quartz, quartzite and mica as non-plastic inclusions; other inclusions, such as volcanics, occur less frequently (Blomster 2004). If some inclusions are rare in the sherd, much depends on where the thin-section is taken.

Table 1: Regional source assignments reported by Blomster et al. (2005: Table 1). Figure 1 indicates locations of the sampled regions. The table does not include 121 analyses from La Venta reported by Neff and Glascock (2002: Table 8), which pertain to a time period after the apogee of San Lorenzo (all of which were attributed to the La Venta region). Also not tabulated are unassigned specimens from the various regions, the interpretation of which is discussed under "statistical issues."

Archaeological Context	**Region as identified by INAA**							
	San Lorenzo	Mazatán	Valley of Oax.	Etlatongo	Tlapacoya	San Isidro	Laguna Zope	Total
San Lorenzo	203	0	0	0	0	0	0	203
Mazatán	23	177	0	0	0	0	0	200
Valley of Oax.	12	0	42	0	0	0	0	54
Etlatongo	35	0	0	26	0	0	0	61
Tlapacoya	17	0	0	0	87	0	0	104
San Isidro	1	0	0	0	0	41	0	42
Laguna Zope	3	0	0	0	0	0	58	61
Total	294	177	42	26	87	41	58	725

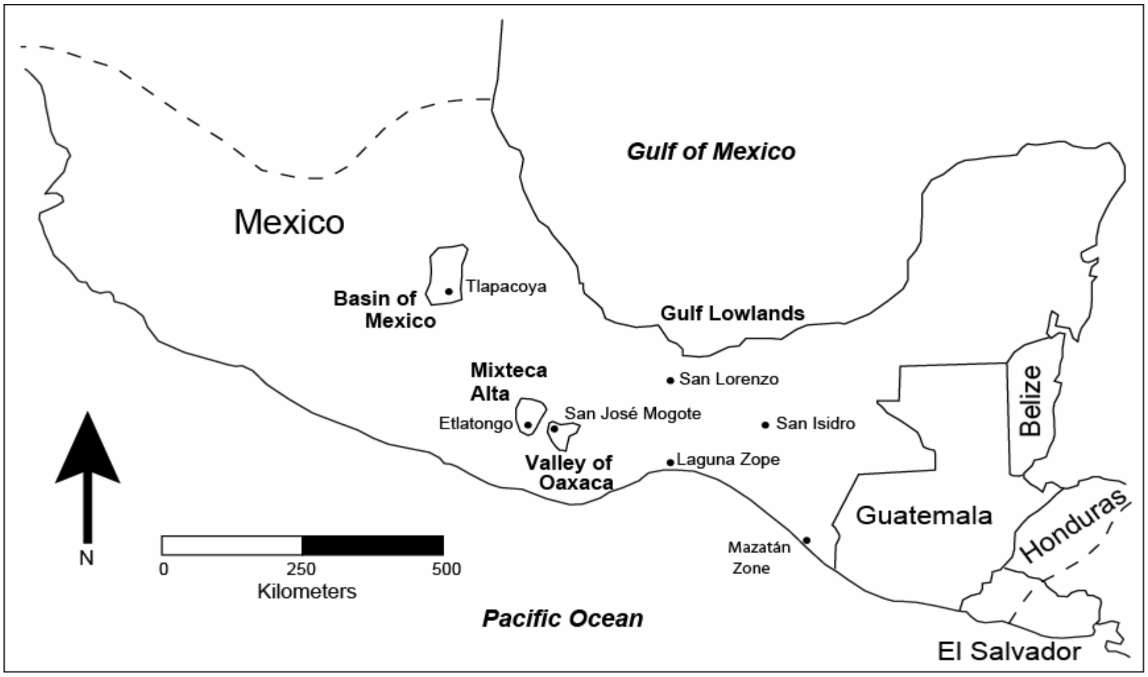

Figure 1: Map of Early Formative regional centers discussed in the text, showing modern national borders for reference. Dashed lines show approximate boundaries of Mesoamerica.

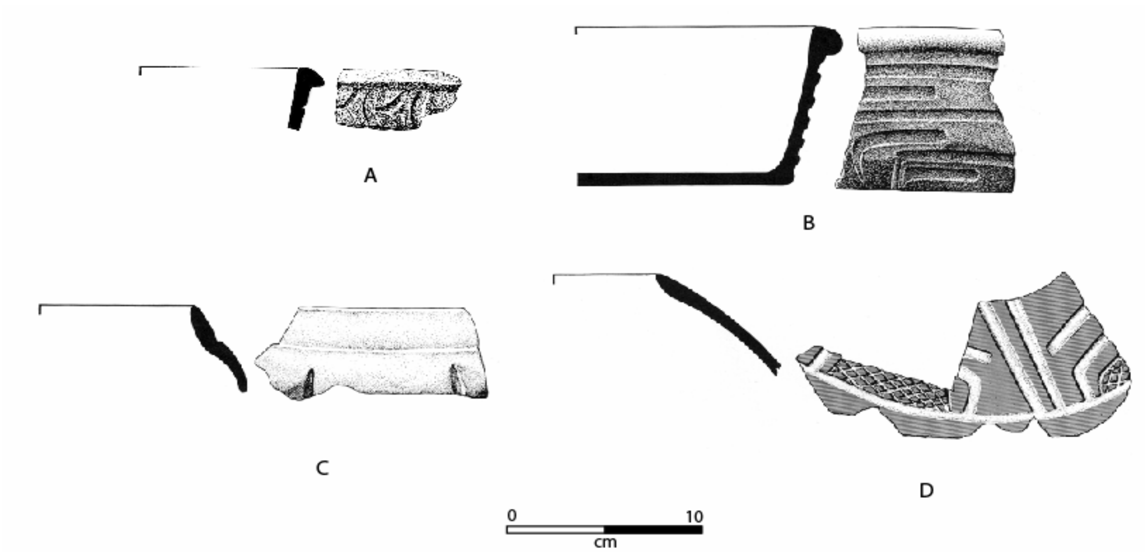

Figure 2: Profile and exterior views of Olmec pottery types produced at San Lorenzo as determined by INAA. A (Sample BLM060) and B represent Calzadas Carved pottery; C (Sample BLM042) is Xochiltepec White; D (Sample BLM041) is Conejo Orange-on-White.

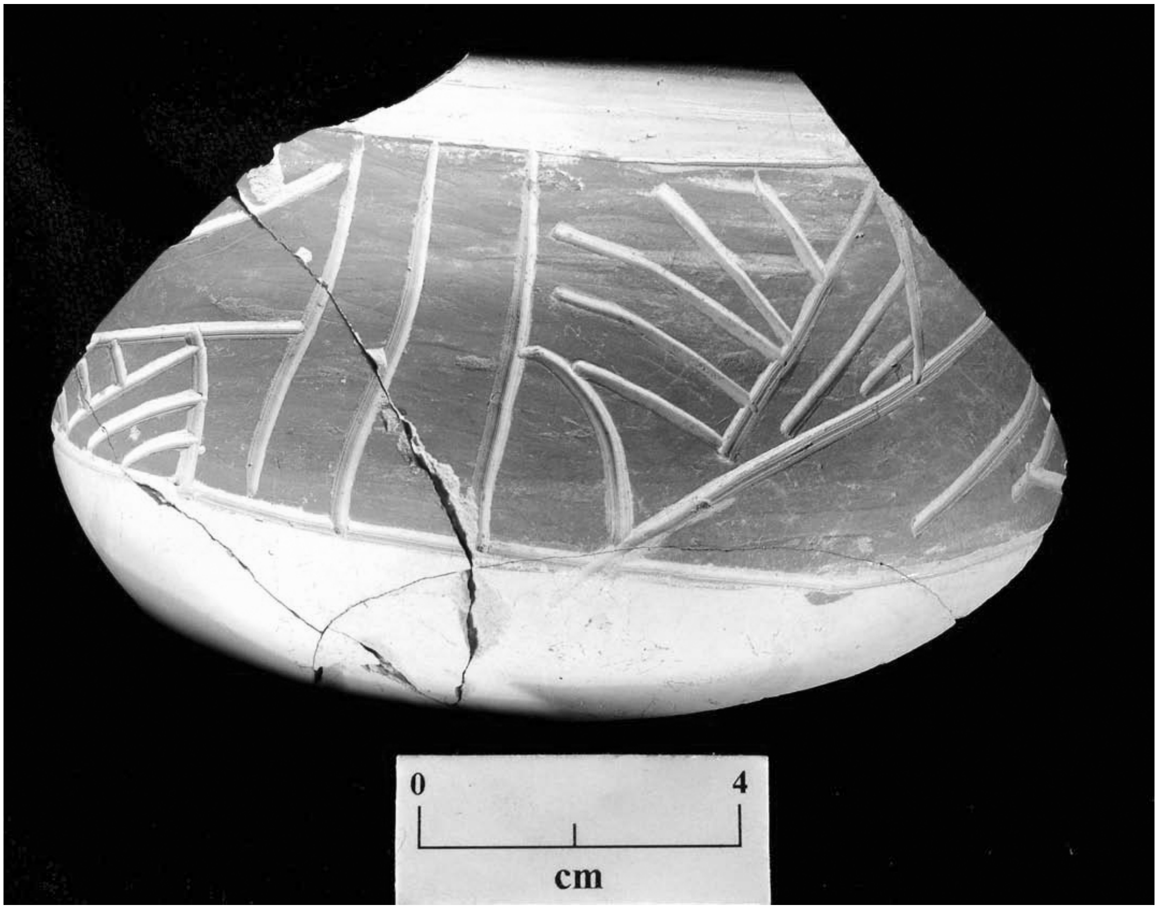

Figure 3: Example of a Conejo Orange-on-White vessel found at Etlatongo but determined by INAA to be an import from San Lorenzo.

Figure 4: Olmec-style Calzadas Carved cylindrical bowl (Sample BLM003) excavated at Etlatongo but determined by INAA to be an import from San Lorenzo.

Figure 5: Two examples of “Delfina Gray” bowls found in the highlands but determined by INAA to be imports from San Lorenzo. Sample on the left (BLM066) is from San José Mogote, Valley of Oaxaca. Sample on the right (BLM028) is from Etlatongo. Carved exterior designs on these sherds are consistent with “Calzadas Carved” pottery from San Lorenzo.

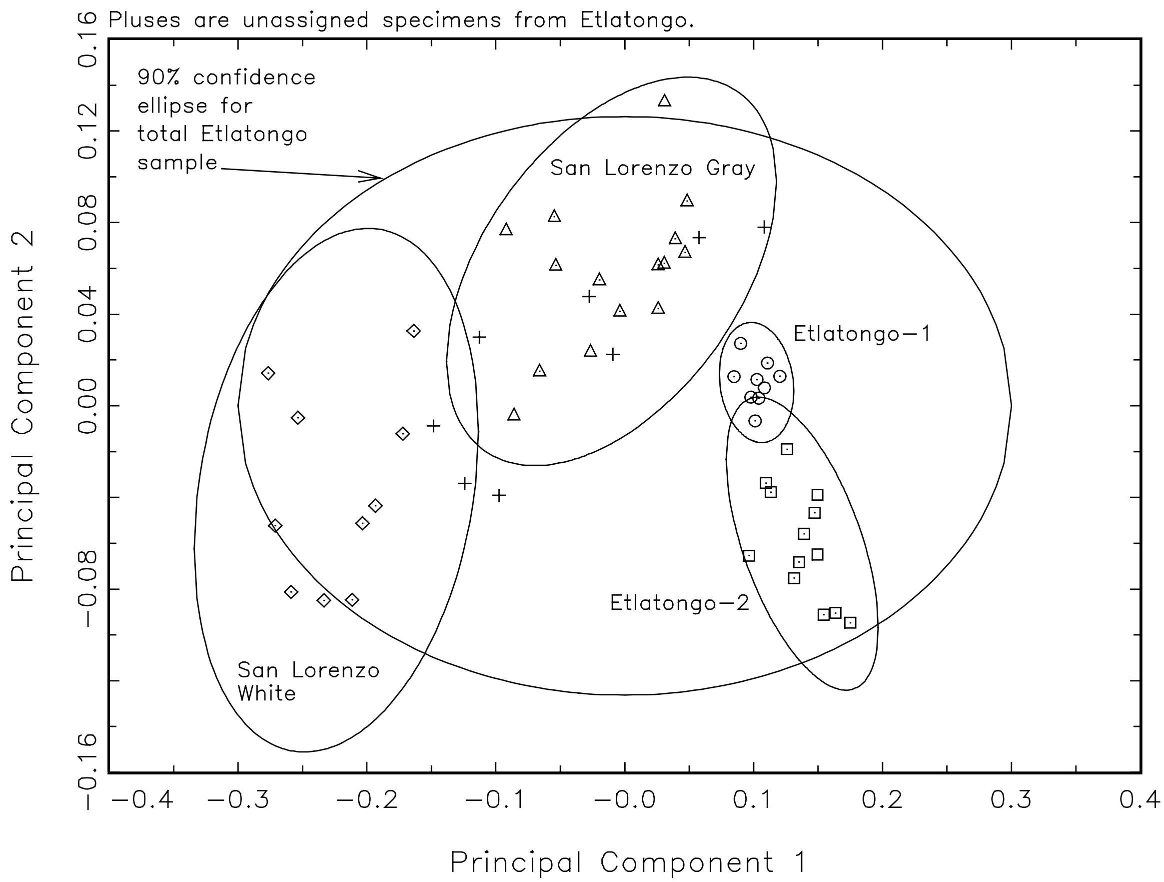

Figure 6: Plot of Components 1 and 2 derived from principal components analysis of the variance-covariance matrix for all analyzed samples from Etlatongo. Small ellipses represent 90% confidence level for membership in the subgroups identified by Neff and Glascock (2002). Large ellipse represents the 90% confidence level for membership in the group consisting of the combined subgroups plus outliers.

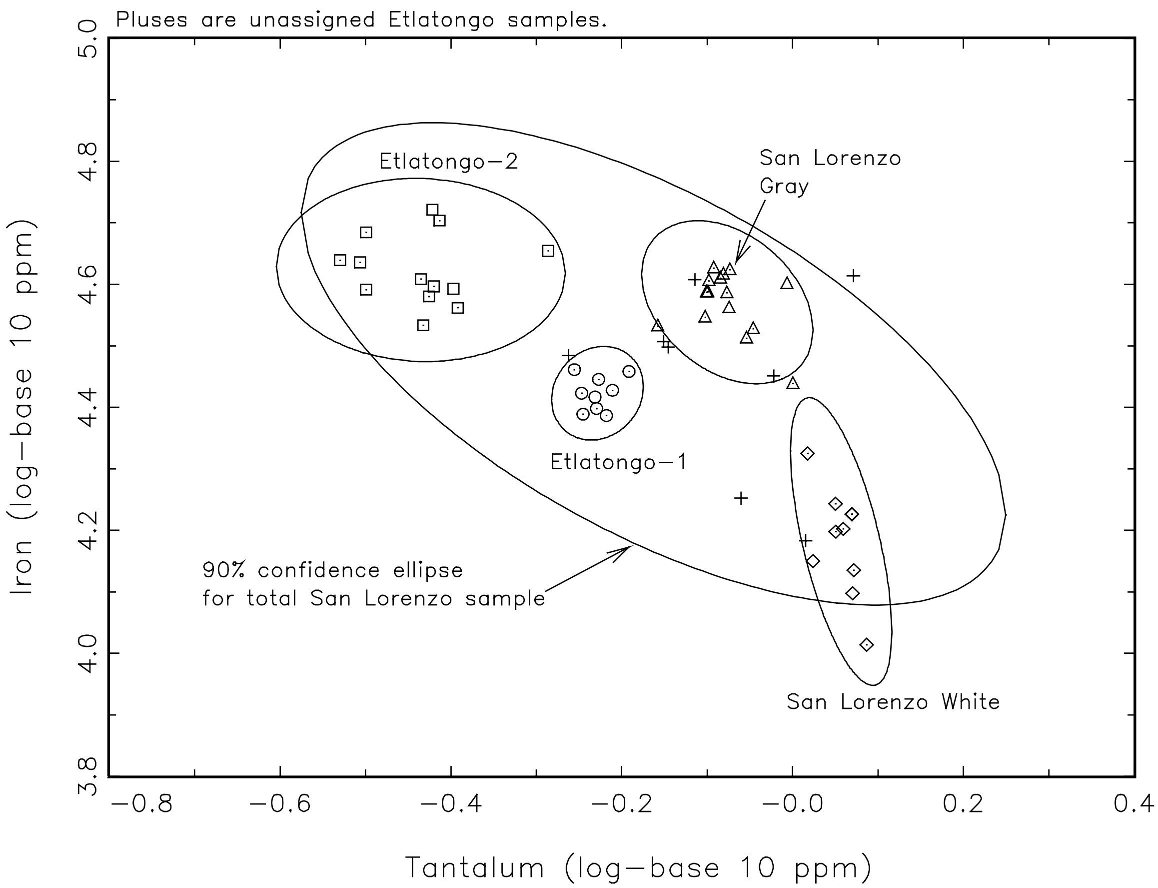

Figure 7: Plot of tantalum and iron concentrations in all analyzed samples from Etlatongo. Small ellipses represent 90% confidence level for membership in the subgroups identified by Neff and Glascock (2002). Large ellipse represents the 90% confidence level for membership in the group consisting of the combined subgroups plus outliers.

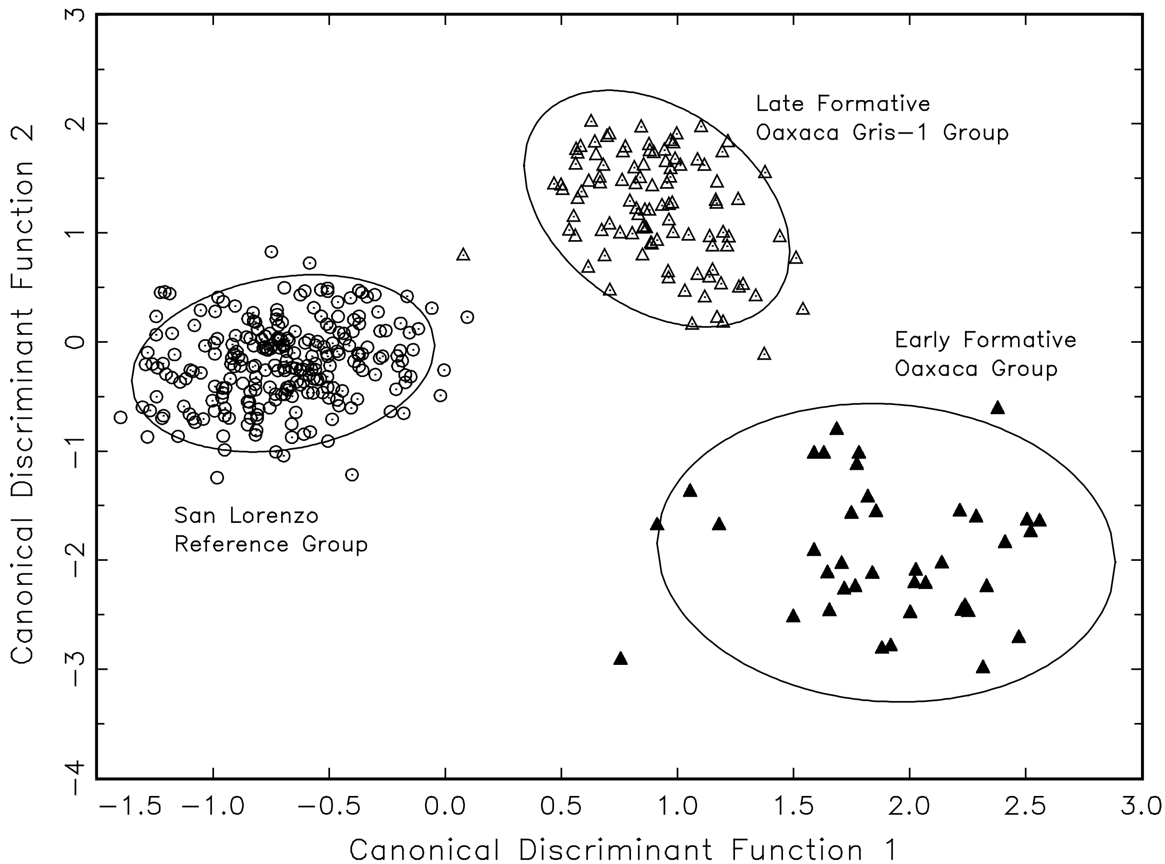

Figure 8: Plot derived from canonical discriminant analysis of the San Lorenzo, Oaxaca Late Formative Gris-1, and Early Formative Oaxaca groups. Ellipses respresent 90% probability of membership in each reference group.