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Production and Distribution of Plumbate Pottery: Evidence from a Provenance Study of the Paste and Slip Clay Used in a Famous Mesoamerican Tradeware

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Introduction

The pinnacle of the potter's craft in the Prehispanic New World was reached around 1100 A.D. by potters living along the Pacific coast near what is today the border between Guatemala and México (Figure 1). In this region, potters of the Late and Terminal Classic periods (600-900 A.D.) and Early Postclassic (900-1200 A.D.) period combined a unique ceramic technology with special raw materials to produce a highly distinctive glazed ware that archaeologists today call "Plumbate." The Early Postclassic

(Tohil) variety of Plumbate ([Figure 2](#), shown below) reached all corners of Mesoamerica and Central America, from Panama to Chichén Itzá to Nayarit. Although previous research has identified the general area where Plumbate originated, the precise locations of raw material sources and production areas and other conditions surrounding the emergence of specialized production for long-distance commerce remain poorly documented.

Plumbate ware has been an object of fascination for explorers, collectors, and archaeologists for more than a century and a half, since Stephens and Catherwood first recorded a shiny gray vessel among the furnishings of a tomb at Zaculeu, in the western highlands of Guatemala (Dutton 1943). The hardness and unusual color of the surfaces probably led to the appellation "Plumbate." However, the implication that Plumbate surfaces have a lead glaze was conclusively disproved by Anna O. Shepard (1948), who found that an unusual, high-alumina, high-iron slip clay combined with partial reduction firing created a vitrified surface with the unusual, gray or olive-green color. Shepard also demonstrated that fancy, Early Postclassic vessels called Tohil Plumbate have a paste that is petrographically distinct from vessels rendered in a simpler style, called San Juan Plumbate.

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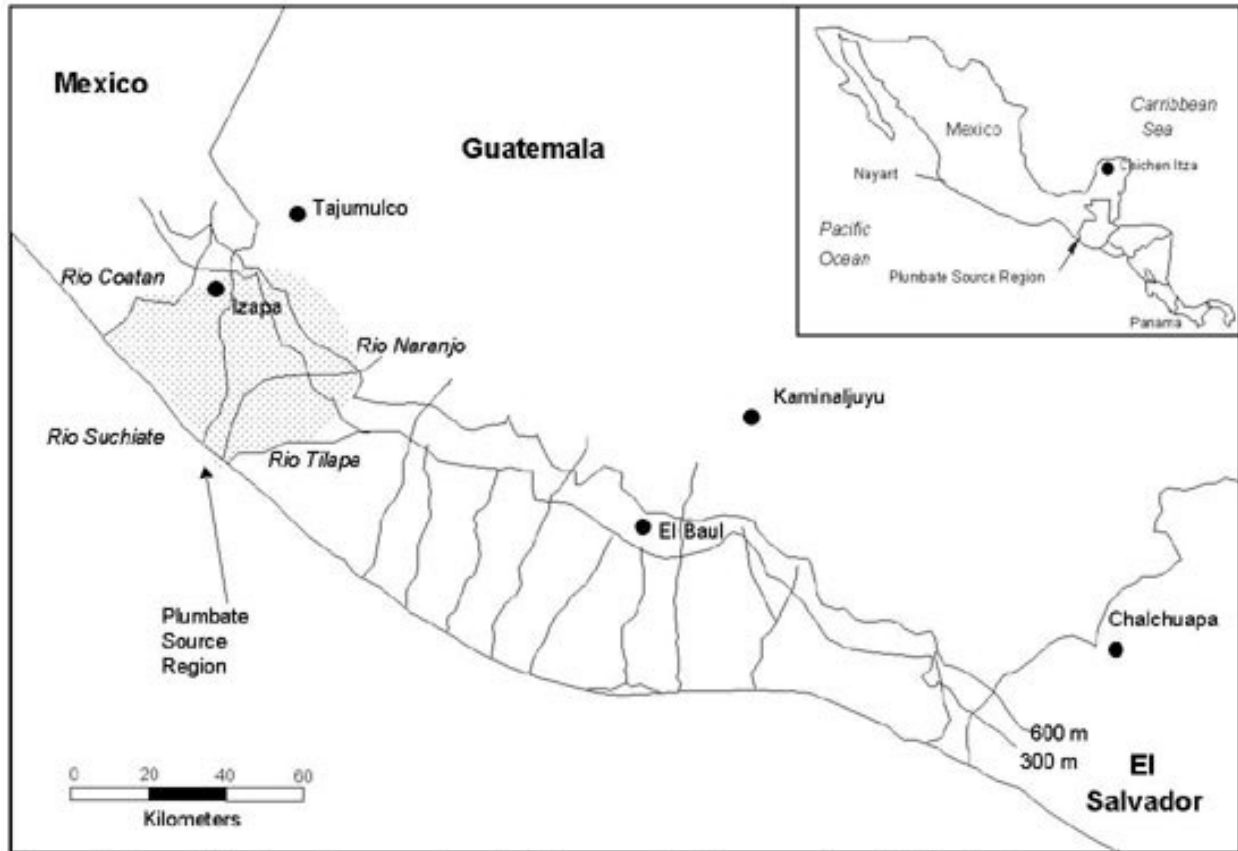Hector Neff
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Figure 1: Map of Southern Mesoamerica showing some locations mentioned in the text.

Figure 2: Tohil Plumbate effigy in the collection of the Museo Popol Vuh, Guatemala.

Previous Research on Plumbate Provenance

Before the 1930s, archaeologists suspected that Plumbate probably came from a single source, and realized that its wide distribution must indicate widespread trade in the ware (e.g., Dutton 1943). Speculation about actual sources ranged from Alta Verapaz, Guatemala (Saville cited in Dutton 1943; Seler 1915, both cited in Dutton 1943) to western El Salvador (Spinden 1915; Lothrop 1927, both cited in Dutton 1943). In the 1930s and 1940s, archaeological findings by Ed Shook (1965) and others (e.g., Dutton and Hobbs 1943; Thompson 1948) demonstrated that the region near the present border between México and Guatemala was the most likely source of Plumbate (see Figure 1). Anna O. Shepard (1948) articulated this hypothesis in her famous monograph, *Plumbate: A Mesoamerican Tradeware*.

Shepard's ceramics research was innovative in its use of petrographic analysis. Her main finding in the case of Plumbate was that there are two distinct pastes, presumably corresponding to two separate sources. At the time her monograph was published, she thought that there was a perfect association of the two pastes with distinct formal categories. Effigy vessels (e.g., Figure 2), miniatures, and vessels with a distinctive style of abstract curvilinear incising, collectively known as Tohil Plumbate, were associated with one paste, while simpler serving vessels such as bowls, cylinders (Figure 3), and composite silhouette vessels, collectively known as San Juan Plumbate, were associated with a second paste. Later, unpublished correspondence (Shepard 1951, 1952) indicates that Shepard found both paste types in sherds of the simpler San Juan style in collections she examined from southwestern Guatemala.
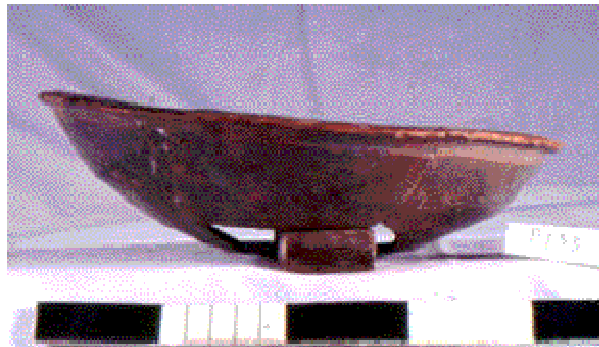

Figure 3: Background tradition ("San Juan") Plumbate vessel in the collection of the Museo Nacional de Antropología e Historia de Guatemala.

Surveys by Shook (1965) and Phillip Drucker (1948) during the late 1940s and 1950s demonstrated that the simpler, presumed earlier style (San Juan Plumbate) was concentrated on the Pacific coastal plain of Southwestern Guatemala rather than in the highlands. Citing this evidence, Shook (1965:190) suggested that Plumbate probably originated between the Río Coatan in southern Chiapas and the Río Tilapa in Guatemala. Other archaeological projects on the coast near the México-Guatemala

border (Coe 1961; Coe and Flannery 1967; Dutton 1958; Lee 1978; Lowe and Mason 1965; Lowe *et al.* 1982) likewise confirmed the high frequency of "San Juan Plumbate" within this region.

Identifying the region where simple Plumbate vessels in the San Juan style originated begged the question of where the fancy Tohil vessels may have originated. Indirect evidence bearing on this issue came to light in the early 1950s, when Shepard examined a collection from the La Gruta excavations at El Paraíso, near Quetzaltenango (Kidder and Shook 1959). Unpublished correspondence (Shepard 1951) indicates that both San Juan and Tohil pastes were found among sherds of the simpler San Juan style in this collection, and that some sherds had both San Juan and Tohil paste constituents. The association of the two pastes fit the hypothesis that all Plumbate came from a single source zone. And, since San Juan Plumbate appeared to come from the Pacific coastal plain, Tohil might come from that region as well. The hypothesis that Tohil was a Pacific coastal product became even more attractive when excavations at Izapa by the New World Archaeological Foundation (Figure 3) encountered whole vessel caches that contained both San Juan and Tohil-style Plumbate vessels (Lee 1973, 1978; Lowe *et al.* 1982).

In the early 1980s, with the encouragement and collaboration of Dr. Ronald L. Bishop, then at Brookhaven National Laboratory, I carried out the first chemical analysis of Plumbate as a dissertation project (Neff 1984; Neff and Bishop 1988). Instrumental neutron activation analysis (INAA) of around 400 sherds confirmed Shepard's division of the ware into two paste classes and added a third, smaller and more geographically restricted paste class. The INAA study also confirmed Shepard's finding that the Tohil style is confined to only one of the paste classes. As Shepard had begun to suspect by the 1950s, however, the simpler serving vessels are not compositionally uniform. In my study, simple vessels in "San Juan" style were found in all three paste compositional variants.

The INAA study also produced some new evidence consistent with Shepard and Shook's hypothesis that Plumbate originated along the coast near the present border between México and Guatemala. Presumed pottery-making by-products from what appeared to be a waster dump in the littoral zone just east of the Río Naranjo (Figure 1) proved to be chemically quite close to the San Juan Plumbate chemical group. Although no direct evidence linking the Tohil chemical group to this region emerged, the high frequency of Tohil pastes on plain vessels, including very large bowls, within this region was most consistent with the inference of local production.

The overall picture that emerged from my study was one in which Late Classic potters at several locations within the México-Guatemala border region were employing similar techniques to make a similar range of serving vessels primarily to meet local demand. Since the widely traded Tohil style of the Early Postclassic period is associated with only one of the paste compositions, I inferred that a localized group of potters within the Plumbate production zone eventually became tied into pan-regional commercial networks. I argued that the stylistic innovations that eventually created Tohil Plumbate

style were a response to the evolutionary challenge of how best to exploit the opportunities offered by non-local markets.

The big thing missing from Plumbate provenance studies undertaken up through the 1980s was analysis of raw materials. A variety of evidence, including analysis of by-products, pointed to the Guatemala-México border region as the likely source of Plumbate, but no direct linkage between the ceramics and raw material sources on the ground had yet been established. Thus, it was unclear whether Plumbate was produced all over this region or only in localized production centers, it was unclear whether San Juan and Tohil compositions derived from the same or different procurement zones, and it was unclear to what extent sources for the slip clay coincided with sources for the body clay. What was clear was that such questions needed to be answered before much could be said about the organization of Plumbate production and its circulation within the region where it was produced. Moreover, future archaeological investigation of Plumbate production facilities would be impossible without more precise information on where Plumbate was produced.

FAMSI Funds a New Investigation of Plumbate Sources

By the late 1990s, two developments, one methodological and one technical, made the time right for revisiting the issue of Plumbate provenance. First, raw material sampling had become an explicit part of the design of ceramic provenance investigations. Research on the central Pacific coast of Guatemala (Neff and Bove 1999; Neff *et al.* 1992), in the Basin of México (Neff *et al.* 2000), on Cyprus (Rautman *et al.* 1999), and elsewhere had clearly demonstrated the value of analyzing argillaceous soils and sediments and comparing them to reference groups of archaeological ceramics. Ethnoarchaeological study (Arnold *et al.* 1991, 1999) had also demonstrated unequivocally that provenance researchers were correct in their assumption that chemical analysis could link manufactured pottery with raw material sources on the ground.

The technical development that promised to contribute toward a better understanding of Plumbate raw material procurement was the introduction in university-based laboratories of laser-ablation inductively-coupled plasma mass spectrometers (LA-ICP-MS). ICP-MS instruments have been used in archaeological provenance research for about the past decade. Coupled to a laser that can be targeted microscopically on spots as small as five microns in diameter, LA-ICP-MS provides a capability for spatially resolved microanalysis of the different components of intact artifacts. In the case of Plumbate, for instance, this new tool could be used to obtain high-precision trace-element data for the slipped surfaces *in situ*.

I submitted a proposal to sample raw materials in the Plumbate source region and to analyze Plumbate surfaces by LA-ICP-MS to the Foundation for the Advancement of Mesoamerican Studies, Inc. (FAMSI) in October, 1998, and received notice of a successful outcome in December, 1998. In the remainder of this report, I describe the

field and laboratory work completed and the results that the investigation has yielded so far.

Ceramic Raw Material Survey on the Pacific Coast Near the México-Guatemala Border

With the help of Sergio Herrera (University of Missouri-Columbia), Ayax Moreno of the New World Archaeological Foundation (NWAF), and Enrique Urisas, I carried out a ceramic raw materials survey in the Plumbate source region during late May and early June, 1999. As in earlier raw material surveys in coastal Guatemala and the Basin of México, our goal was to sample a wide range of argillaceous soils and sediments, in order to maximize the probability that some of our samples would fall within the range of variation of the Plumbate reference groups. In some cases, we sampled clays being exploited for production of bricks for construction (Figure 4, shown above). More often, we sampled clay beds exposed in cut banks, wells, stream cuts, road cuts, drainage ditches, or other kinds of construction excavations (Figure 5, shown below). When we could not find suitable existing exposures, we used a bucket auger to obtain subsurface samples (Figure 6, shown below). We also collected various kinds of tempering material. We ended up with a total of 207 clays from 132 locations and 29 tempers from 28 locations (Figure 7).

Figure 4: R. Sergio Herrera records clay samples collected from a brick-making operation south of Tapachula, Chiapas, México.

Figure 5: Hector Neff and Ayax Moreno obtain clay samples from a construction excavation southwest of Tapachula, Chiapas, México.

Figure 6: Enrique Urisas and Leonel Urisas demonstrate the use of a bucket auger for obtaining clay samples.
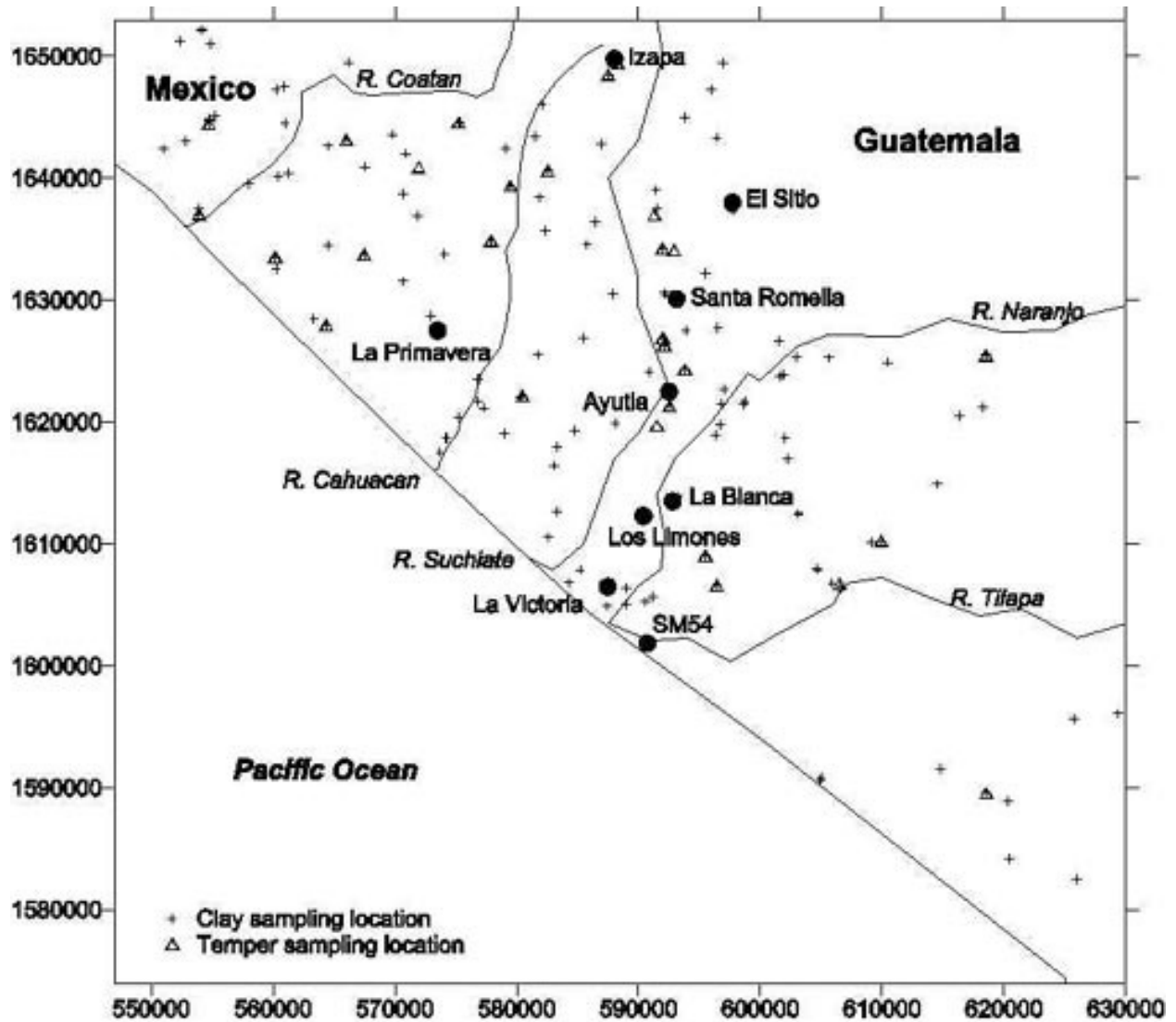
Figure 7: Map showing raw material locations and some archaeological sites with Plumbate in the México-Guatemala border region.

Laboratory Analysis

The clays and tempers sampled during the survey were taken back to the archaeometry laboratory at the MU Research Reactor (MURR), where they were prepared for analysis. The clays were mixed with de-ionized water, pressed into petrie dish molds, then fired to 700 degrees for one hour in air before being prepared for analysis. Aliquots of each test tile were prepared for INAA by crushing several hundred milligrams in an agate mortar to yield a fine powder. The remainder of each specimen was left intact for analysis by LA-ICP-MS. Intact pieces of Plumbate pottery that had previously been

analyzed by INAA were retrieved from the MURR ceramic paste archive for analysis by LA-ICP-MS.

Instrumental Neutron Activation Analysis

For INAA, the powdered clay test-tile samples were oven-dried at 100 degrees C for 24 hours. Portions of approximately 150 mg were weighed and placed in small polyvials used for short irradiations. At the same time, 200 mg of each sample were weighed into high-purity quartz vials used for long irradiations. Along with the unknown samples, reference standards of SRM-1633a (coal fly ash) and SRM-688 (basalt rock) were similarly prepared, as were quality control samples (i.e., standards treated as unknowns) of SRM-278 (obsidian rock) and Ohio Red Clay.

INAA of ceramics at MURR, which consists of two irradiations and a total of three gamma counts on high-purity germanium detectors, constitutes a superset of the procedures used at most other laboratories (Glascock 1992; Neff 2000). A five-second irradiation through a pneumatic tube system, which is followed by a 720-second count, yields gamma spectra containing peaks for the short-lived elements aluminum (Al), barium (Ba), calcium (Ca), dysprosium (Dy), potassium (K), manganese (Mn), sodium (Na), titanium (Ti), aluminum and vanadium (V). A 24-hour irradiation is followed by a seven-day decay, then a 2,000-second gamma count (the "middle count"), then an additional three- or four-week decay, and, finally, a count of 9,000 seconds. The middle count yields determinations of seven medium-halflife elements, namely arsenic (As), lanthanum (La), lutetium (Lu), neodymium (Nd), samarium (Sm), uranium (U), and ytterbium (Yb), and the final (long) count yields measurements of 17 long-halflife elements, namely cerium (Ce), cobalt (Co), chromium (Cr), cesium (Cs), europium (Eu), iron (Fe), hafnium (Hf), nickel (Ni), rubidium (Rb), antimony (Sb), scandium (Sc), strontium (Sr), tantalum (Ta), terbium (Tb), thorium (Th), zinc (Zn), and zirconium (Zr).

The same basic MURR INAA procedures outlined above had been employed previously in the analysis of Plumbate sherds recovered from Classic period sites on the central Pacific Guatemalan coast (Neff 1995). These analyses confirmed the findings reported in the earlier Plumbate study (Neff 1984; Neff and Bishop 1988), namely that Plumbate found outside the production region separates into two distinct chemical groups, San Juan and Tohil. Earlier INAA data from BNL were used to check results obtained using the MURR data, but, since fewer elements were determined at BNL, most comparisons relied only on the more complete MURR data.

Analysis of Plumbate Surfaces and Clay Test Tiles by LA-ICP-MS

Although INAA has been the workhorse characterization technique used in archaeological provenance investigations for the past 35 years, decommissioning of research reactors and phasing out of archaeological INAA programs has severely curtailed the availability of INAA. This trend is likely to limit INAA to a quality-control

role in archaeometry within the coming decade (Neff 2000). Fortunately, the analytical scene is currently being revolutionized by the advent of highly precise and sensitive characterization techniques based on inductively coupled plasma-mass spectrometry (Kennett *et al.* 2001). In ICP-MS, a plasma torch capable of sustaining an argon plasma at temperatures above 8000° C is used to ionize injected samples, which are then sent into a quadrupole or magnetic-sector device, where they are separated according to mass and charge, so that the detector at the other end records only a very small atomic mass range at a time. By varying instrument settings, the entire mass range can be scanned within a short period of time.

Recognizing both the potential advantages for archaeology of proliferating ICP-MS instruments on university campuses and the potential pitfalls inherent in the changing analytical scene, Mike Glascock and I wrote a NSF grant in 1999 to obtain a high-resolution magnetic-sector ICP-MS instrument for the MURR archaeometry laboratory. Our funding effort was successful, and in June 2000 a Thermo-Elemental (formerly VG Elemental) Axiom magnetic-sector ICP-MS was installed at MURR. A schematic diagram of a magnetic sector ICP-MS is shown in Figure 8.
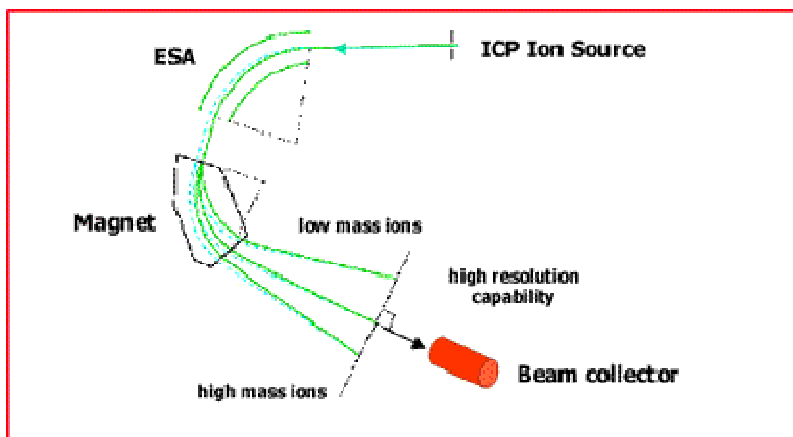

Figure 8: Schematic diagram of a magnetic-sector ICP-MS instrument like the Thermo-Elemental Axiom recently installed at MURR.

In the Axiom, the ion beam is focused on a collector slit that can be tuned so that masses as close as 0.001 atomic mass units can be resolved from one another. This gives the Axiom the capability to resolve a large number of polyatomic interferences that would be completely unresolvable with quadrupole instruments, thus dramatically increasing instrumental sensitivity and precision. In liquid samples, the instrument is capable of measuring sub-ppb amounts of the vast majority of elements.

Since the first archaeometric uses of ICP techniques in the early 1980s (e.g., Hart and Adams 1983; Hart *et al.* 1987), most applications have required digestion of solid samples with heat and/or strong acids, which is both time-consuming and unpleasant.

An alternative sample-introduction technique, which became available in the early to mid-1990s, is laser ablation (Pollard and Heron 1996; Campbell and Humayun 1999). In this approach, a pulsed laser ablates a small portion of a solid sample, and the resulting vaporized solid is then sent into the ICP torch. In principle, LA-ICP-MS can be used to generate bulk compositional data on solid samples without chemical digestion. In practice, there are a number of obstacles related to data standardization that currently limit the extent to which LA-ICP-MS will compete with bulk techniques, such as INAA or digestion ICP-MS.
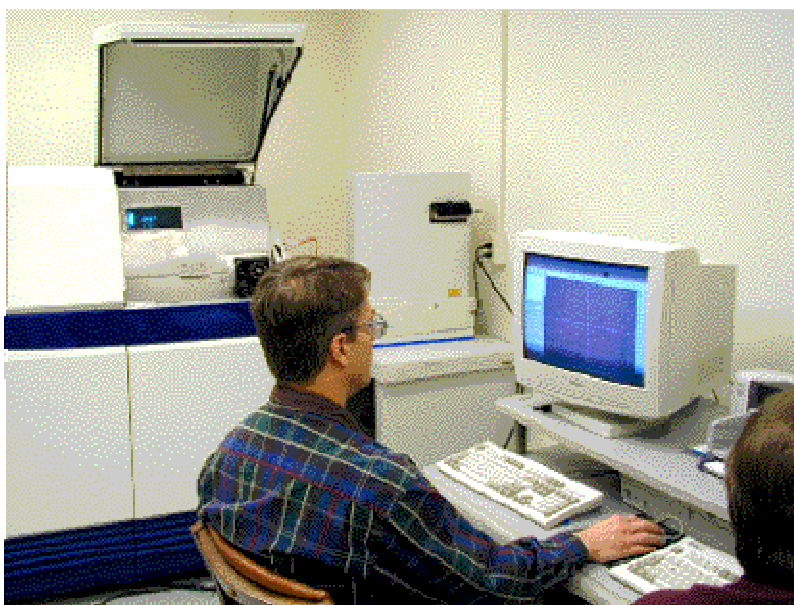

Figure 9: The Axiom (background left) and the laser-ablation system (background right) are controlled by separate PCs.

The other strength of laser ablation is its capability to do spot analysis (or microanalysis) of spatially segregated components in the artifact fabric. Thus, separate analyses can be obtained for individual temper grains and/or for areas of clay matrix that contain no temper grains. For the clay test tiles analyzed in this study, areas of matrix free of non-plastics were targeted for analysis (Figure 9 and Figure 10). Since each pass of the laser only ablates about five microns or so of material, slipped and pigmented surfaces can be analyzed in situ simply by placing a sherd fragment in the laser chamber with the slipped surface facing the laser beam. This is the approach that was used for the analysis of Plumbate slip materials.
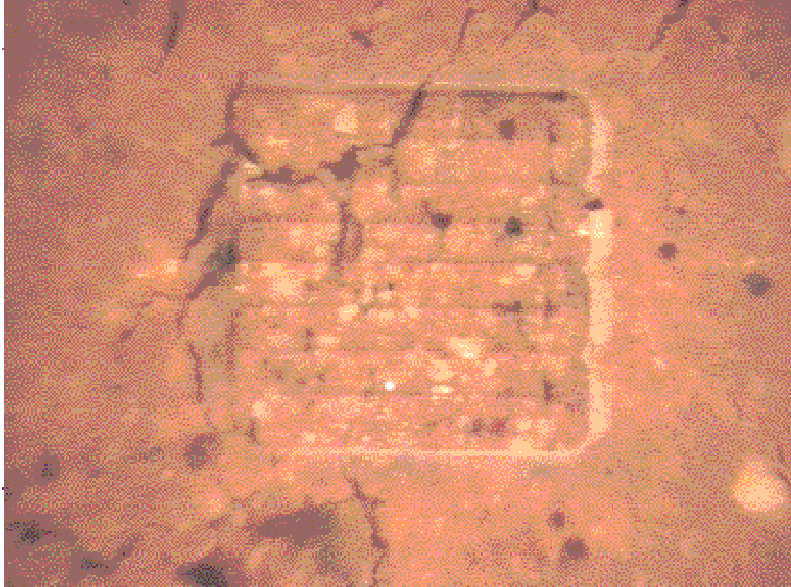
Figure 10: Close-up of clay test tile after laser ablation. The spacing of the rows is 95 microns, and the spot size was 100 microns, so there is slight overlap of the rows.

The study of Plumbate surfaces was one of the first conducted on the new Axiom at MURR. Thus, approaches to standardizing the data had to be worked out from scratch. A basic problem in LA-ICP-MS is that it is difficult to monitor the amount of material removed by the laser and sent to the ICP. Conditions such as hardness of the material, position of the sample in the laser chamber, whether or not it is level, and other conditions clearly affect how much material reaches the torch and thus the intensity of the signal monitored for the various atomic masses of interest. In addition, instrumental drift in the ICP-MS affects count rates.

With liquid samples, internal standards are typically used to counteract instrumental drift, but this approach is not available when the material for analysis is ablated from an intact sample. If one or more elements can be determined or assumed independently, then these can serve as quasi-internal standards. For instance, rhyolitic obsidian has relatively consistent silica concentrations, and we have found that ratios of count rates to the silicon count rate yields "normalized count rates" that can be calibrated using external standards so as to yield concentrations that are in good agreement with INAA and XRF measurements.

The internal heterogeneity of clays and the diversity of materials used in ceramic manufacture preclude assuming a value for any single component, such as alumina or silica, in the Plumbate study. Another approach would be to measure one or more major oxides with some other surface technique, such as XRF, then use the independent measurements to normalize the LA-ICP-MS data in order to correct for differential ablation and instrumental drift. However, this approach would still suffer from the problem of within-sample heterogeneity, and it basically doubles the analytical effort. One approach that did yield results in reasonably good agreement with INAA data for

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several clays of known composition was to normalize the count rates for each element so that they sum to a single standard value, e.g., one million, for all standards and unknowns. A regression of normalized counts on elemental concentration in the standards then yields a calibration equation that can be used to calculate elemental concentrations in the unknowns. The basic assumption of this approach is that the 43 elements being measured represent essentially all of the material, other than oxygen, that is ablated from the samples. We tried incorporating corrections for isotopic abundance and for difference in resolving power between the measured elements, but these had little effect on the calculated elemental concentrations. The one correction we did have to make was for the overwhelmingly larger aluminum counts, a reflection both of its relatively high concentrations in the clays and of the fact that it can be measured at low resolution.

Results 1: Raw Material Sources for Plumbate Pastes

The Plumbate sherds analyzed by INAA since 1993 at MURR showed the same basic chemical patterning reported previously by Neff (1984; Neff and Bishop 1988). That is, the vast majority of analyzed specimens fall into one of two compositional groups, designated San Juan and Tohil in recognition of consistent typological differences. Sherds of San Juan composition are exclusively "background tradition" bowls, cylinders, large jars ("Robles jars"), and large everted rim vessels of various shapes. The Tohil group not only includes background tradition vessels, but also lamp chimneys, Tohil jars, effigies, figurines, and other forms typical of the fancy Tohil style (see Neff 1984 for descriptions). Chromium and iron concentrations (Figure 11, below) easily discriminate the compositional groups, as do many other bivariate plots of the INAA data. Figure 11 also shows iron and chromium concentrations determined by INAA in the raw clays from the Plumbate production region. Although the clays are generally much more variable than the pottery, a number of clay samples fall within the ranges of variation of both reference groups on these axes. More detailed identification of where the two groups might originate within the Plumbate production region must be based on a similarity assessments obtained from a broader range of elemental concentrations data.
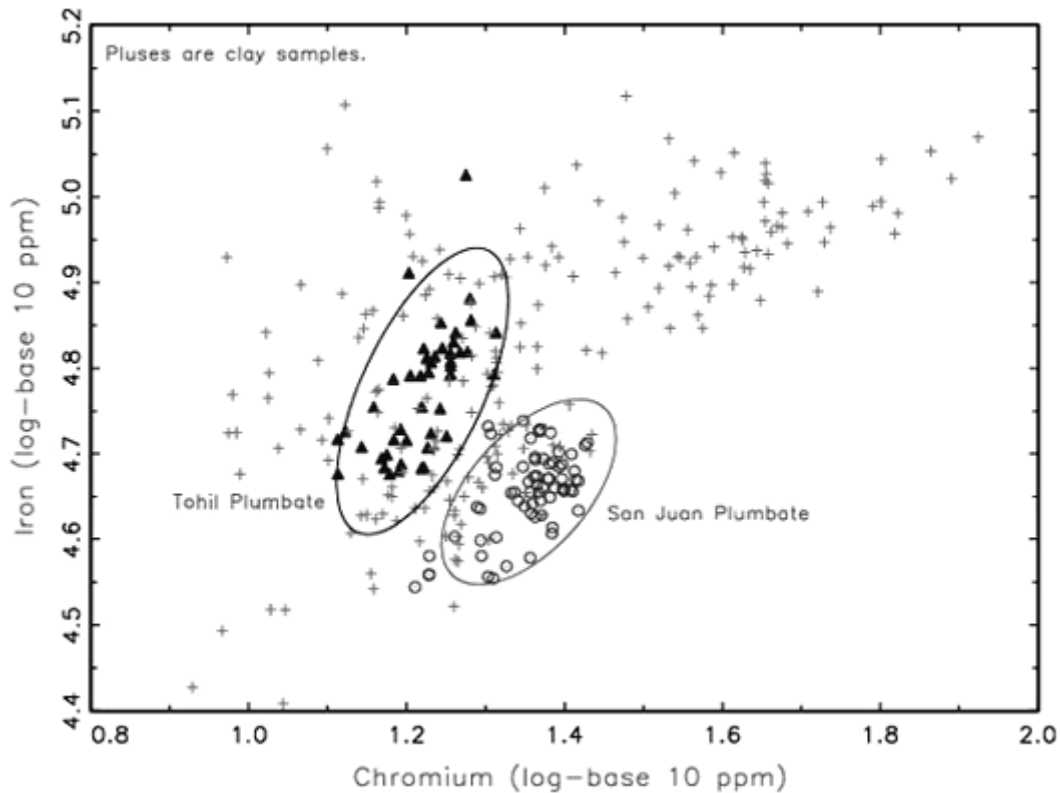
Figure 11: Iron and chromium concentrations determined by INAA in San Juan and Tohil Plumbate together with raw clay samples from the Plumbate production region.

With well-defined reference groups such as those shown in Figure 11, provenance determination resolves to a search for locations where there are raw clays that fall within the range of chemical variation of the two groups (Neff 1998, 2001; Neff and Bove 1999). Whether a clay falls within the range of variation of a group can be measured by its multivariate proximity to the group centroid (the Mahalanobis distance), which can be expressed as a probability of group membership. These point probabilities can be used to estimate a probability surface for the sampled region; peaks or plateaus on the surface are the areas most likely to have clays that fall within the range of chemical variation of the group.

Probabilities for the clays can be generated using different subsets of the samples and different subsets of elements. Based on the MURR data and using elements that best discriminate the two groups, the San Juan source is placed on the east side of the border, near the mouth of the Río Naranjo (Figure 12), and the Tohil source is placed on the west side of the international border, along the Río Cahuacan (Figure 13). Probability surfaces based on much larger reference groups consisting of MURR data together with the BNL data and using different subsets of the elements are configured a little differently, but still place the San Juan and Tohil source zones in the same areas.

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Comparison of the raw clays collected in the Plumbate source region with the Plumbate reference groups thus leads to a highly specific understanding of the provenance of the two Plumbate pastes. The San Juan and Tohil source zones do not overlap, and both are quite localized on the lower coastal plain near the present México-Guatemala border. Most of the sites in the region where large quantities of Plumbate are found, such as Santa Romelia, El Sitio, and Izapa, appear to lie outside of either of the two zones where Plumbate was produced.
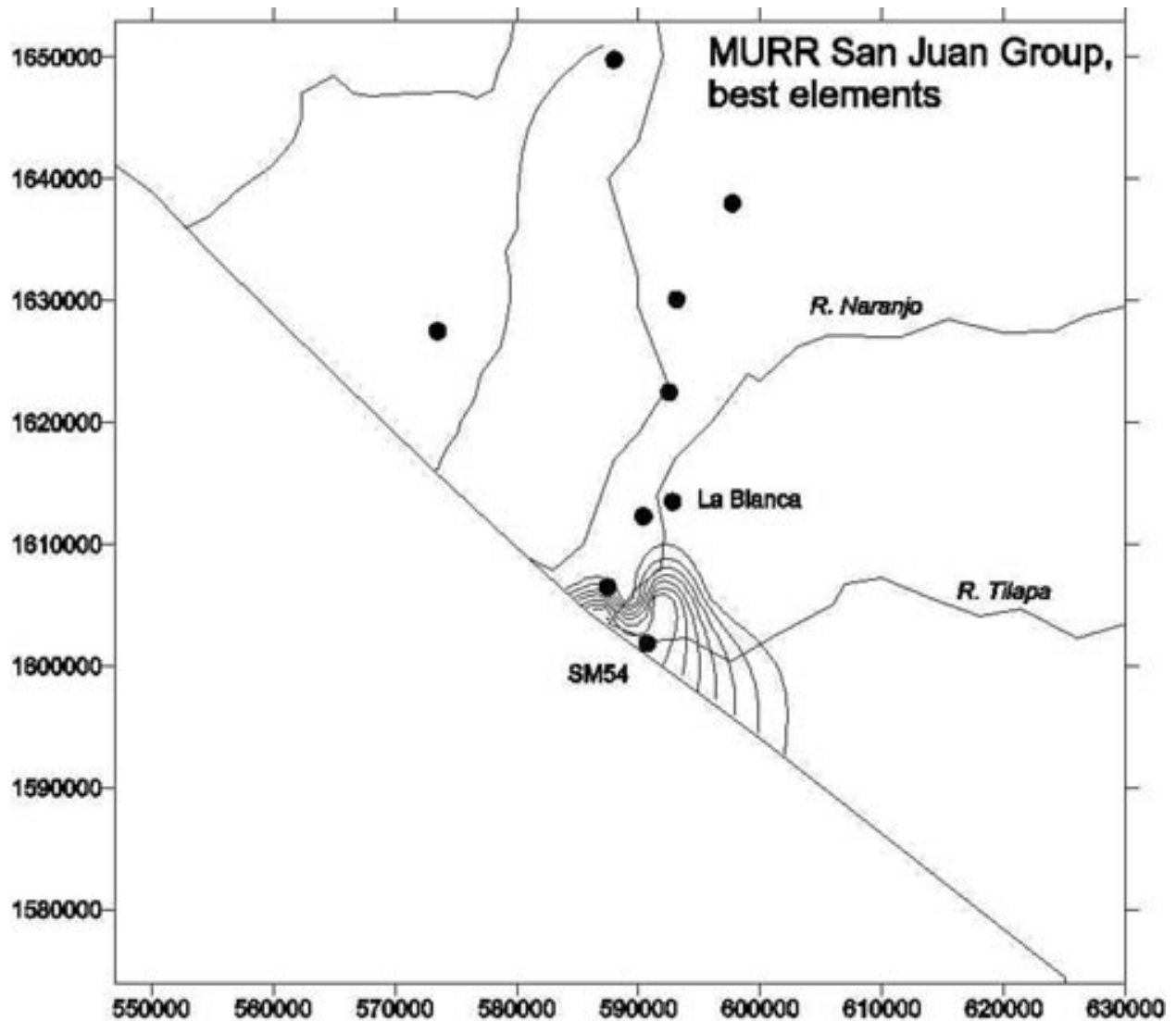

Figure 12: Source zone map for San Juan Plumbate based on concentrations of La, Lu, Nd, Sm, Yb, Ce, Cr, Eu, Fe, Hf, Sb, and Dy.
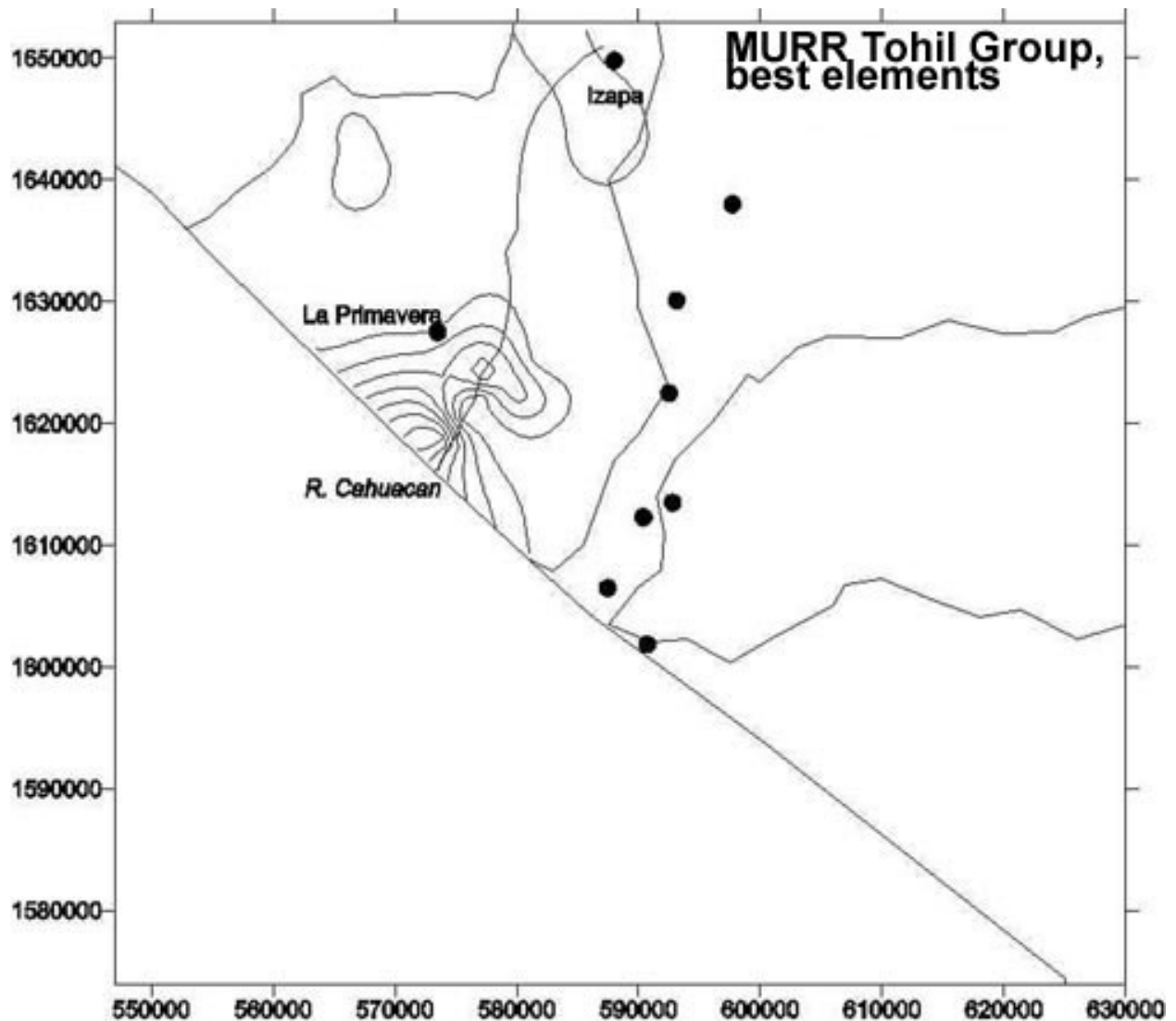
Figure 13: Source zone map for Tohil Plumbate based on concentrations of La, Lu, Nd, Sm, Yb, Ce, Cr, Eu, Fe, Hf, Sb, and Dy.

This new evidence finally puts to rest any doubt about where the fancy Tohil plumbate vessels found in tombs and offerings all over Mesoamerica were produced. The Tohil Plumbate compositional group, which includes vessels in this fancy style, is now clearly linked with raw materials sampled along the lower reaches of the Río Cahuacan in southern Chiapas, México. Observations made during our raw materials survey indicate that Plumbate sherd densities are extremely high in the banana fields that dominate the modern landscape on this part of the coastal plain. Future work will be aimed at locating and excavating firing areas and other production facilities within this region.

Results 2: Plumbate Slips and Their Raw Material Sources

The same methods used to identify sources of the San Juan and Tohil Plumbate body pastes can also be used to compare the LA-ICP-MS compositional data obtained for the raw clays with reference groups defined based on analysis of the slips. First, however, it is necessary to define slip material reference groups. One reasonable hypothesis is that the same raw material sources were used for both paste and slip clays, in which case we should find that the slip material reference groups correspond precisely with the body paste reference groups discussed above. One alternative to the hypothesis that slip and body clay are one and the same is that a single, unique slip raw material was used by both San Juan and Tohil potters. Another possibility is that San Juan and Tohil potters used multiples sources of slip clay, so that there will be more than just two reference groups of slip clay material. Even if two reference groups are identified, it is possible that these may not correspond precisely to the paste reference groups. Determining which of these various alternative hypotheses can and cannot be rejected will have important implications for the organization of Plumbate raw material procurement, regardless of where the source zone or zones are located.

In order to develop an analytical protocol for the laser-ablation ICP-MS analysis of Plumbate surfaces, several exploratory analyses were undertaken. First, a number of sherds were cross-sectioned and examined under a scanning electron microscope (SEM). As one example, the backscattered-electron (BSE) SEM image shown at the top of Figure 14 shows a section through a Tohil Plumbate sherd, CPA1120. The surface material is both denser and brighter than the underlying paste. The thickness of the surface can be estimated at approximately 30-50 microns based on the BSE image. The brightness indicates that the slip is characterized by generally higher concentrations of heavier (higher atomic number) elements. The bottom of Figure 14 is an x-ray dot map, which identifies iron as one of the elements that is enriched in the surface material. In some cases, a darker band <10 microns in thickness on the BSE image indicates a layer of light-element enrichment on the uppermost zone of the slip material (Figure 15). Based on SEM examination of cross-sections of four San Juan and four Tohil Plumbate sherds, we estimate that the thickness of the slip varies from about 30 microns to about 80 microns. The sensitivity of the energy-dispersive detector in the SEM was insufficient to detect consistent differences in other elements.
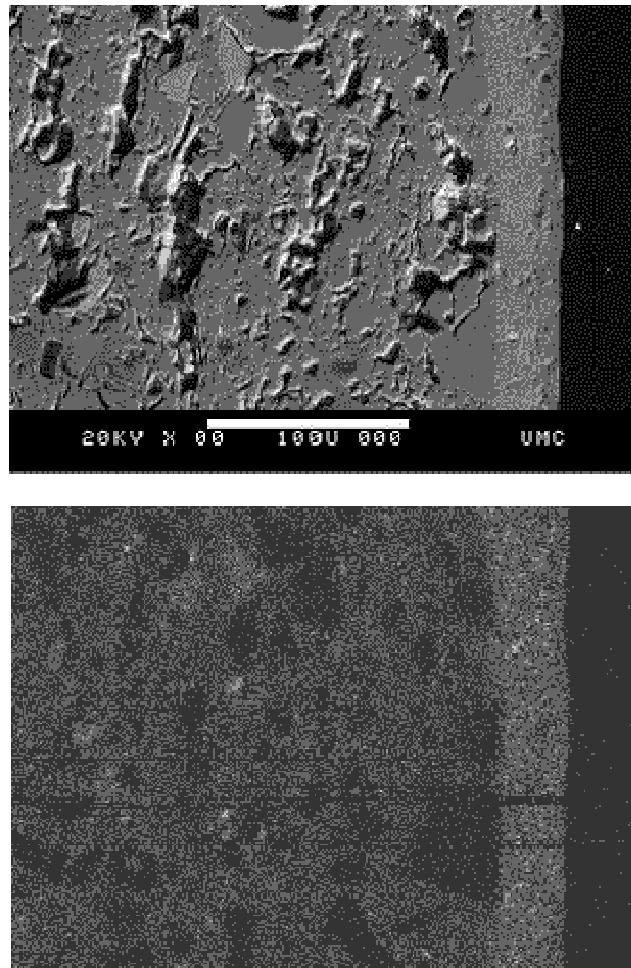
Figure 14: (top) BSE image of a cross-section of Tohil Plumbate sherd CPA1120. (bottom) X-ray dot map of iron concentrations across the same area shown in top image; brighter areas are enriched in iron.

The SEM examination thus demonstrates that Plumbate slip material is finer in texture and enriched in some elements compared to Plumbate body pastes. These differences might result either from use of distinct slip clay sources or from clay refinement, which produced the finer texture as well as the enriched concentrations of heavier elements.

The compositional zonation detected within the slip material (e.g., the narrow dark band on the outermost zone of the slip on CPA1076 [Figure 15]) suggests that there are systematic variations in composition with depth within the slipped surface layer. This observation prompted a more detailed LA-ICP-MS study of compositional variation within the slipped surfaces. Among other things, since the SEM examination clearly shows that composition of the outer few microns is distinct from the underliying slip, it is necessary to decide how much of the surface to ablate away before taking the measurements used for characterizing each slip.
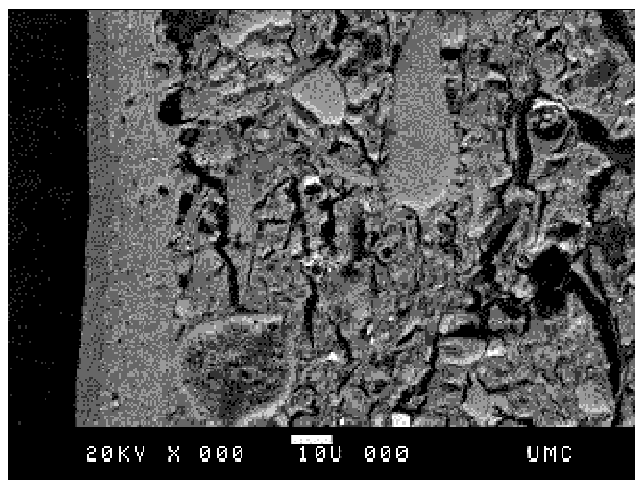
Figure 15: BSE image of cross-section of San Juan Plumbate sherd CPA1076.

The detailed LA-ICP-MS analysis involved taking depth profiles by measuring elemental concentrations during separate individual ablation passes over the same raster area. It is estimated that the laser ablates four to five microns on each pass, so each successive pass will give the elemental concentration for a slice of the slip material approximately five microns deep. Because of the likelihood that technological differences would affect both the nature of chemical zonation and the ease with which the laser ablated the surface, a number of surfaces of varying colors and apparent hardness were depth-profiled in this manner. Thus, for each sherd, we obtained between 20 and 40 data points, each datapoint representing a distinct 'layer' within the surface material. With respect to the provenance analysis, the main goal at this stage of the analysis was to decide how many pre-measurement ablation passes to make with the laser prior to initiating the collection of data for characterization of each sherd.

The depth profiling experiments revealed systematic changes in composition with depth. Principal components analysis of the data from successive passes across the same spot on a sherd (e.g., Figure 16) show, for instance, that successive passes form a clear series, with adjacent passes grouped together. In all cases, the first several passes diverge markedly from successive passes. In most cases, such as the shiny gray side of Tohil Plumbate specimen CPA1036 (Figure 16), divergence of the surface layers is due to enrichment of a number of elements, in most cases including copper, zinc, sodium, potassium, and chromium.
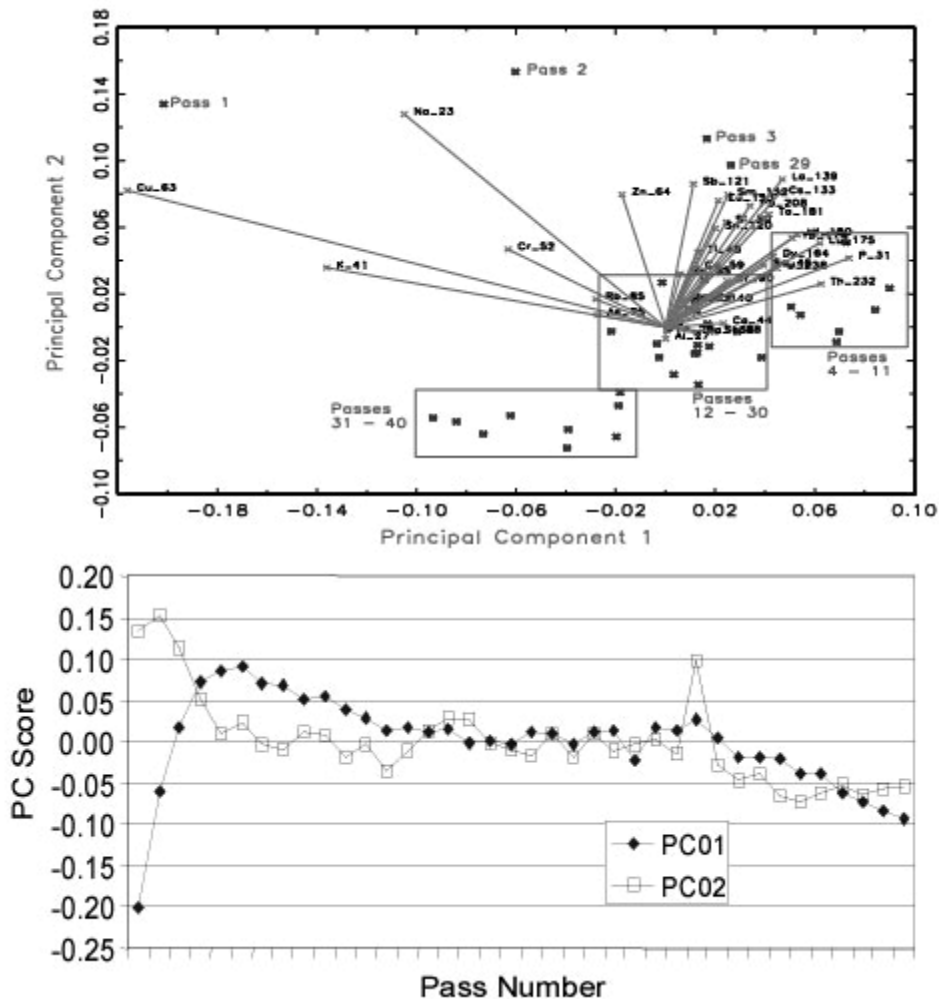
Figure 16: Principal components analysis of data produced by successive passes over the same raster on the shiny gray side of Tohil Plumbate specimens CPA1036. (Top) RQ-mode PCA. (Bottom) line plot of PC1 and PC2 scores.

Figure 17 confirms that copper and chromium levels are elevated in the surface layer of CPA1036. This particular depth profile is interesting because it also shows that copper levels in the layer immediately beneath the surface (Passes 4-11) are slightly depleted in copper compared not only to the surface but also to deeper layers. This can also be seen in the PCA results (Figure 16), where the highest scores on PC1, which are negatively correlated with copper, are found in Passes 4-11. Since the enriched copper at the surface is compensated by depleted copper in the underlying layer, we can infer that chemical zonation within the slip is due to elemental mobilization, which most likely occurred as the clay-mineral structure broke down in the high temperature environment of the kiln. Thus, while other mechanisms of surface enrichment, such as diagenetic additions in the burial environment, might be hypothesized, the chemical zonation observed in Plumbate surfaces is most consistent with the hypothesis of pyrotechnology-induced change.

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The depth-profiling experiments confirmed that measurements made on the first several laser passes would be unlikely to yield data that could be used in a provenance investigation. Results of a number of such experiments on surfaces of different colors and different apparent hardness suggested that measurements changed only gradually between Pass 4 and Pass 17 in most specimens. In many specimens, measurements below Pass 17 or 18 appeared to change more rapidly, presumably as they became increasingly affected by the underlying body paste (e.g., Figure 16). Based on these observations, the strategy adopted for collecting the Plumbate surface data to be used in the provenance investigation was to ablate four passes at relatively high power (thus ablating perhaps as much as would be ablated in 6 or 8 passes at a lower power setting), then to collect the data at the lower power setting on Pass 5 through Pass 8 or Pass 9, depending on the size of the ablated area. Additionally, the depth profiling suggested that several elements, especially copper, chromium, and sodium, which are clearly redistributed within the slip during firing, should not be used for comparison with raw clays. Data were collected on a total of 145 Plumbate specimens in this way. Body paste samples from all of these specimens had been analyzed previously by INAA.

Although the LA-ICP-MS data on Plumbate surfaces do not subdivide into groups as cleanly as do the body paste INAA data, two distinct chemical groups can be discerned on a number of projections of the data (e.g., Figure 18), and Mahalanobis distance calculations confirm that these groups are well-discriminated in multivariate elemental concentration space. There is also an extremely close, although not perfect, correspondence between the groups identified in the paste data and the groups identified in the surface data (Table 1). The latter observation indicates either that potters using Tohil body paste sometimes (less than 5% of the time) used San Juan slip clay and that potters using San Juan body paste sometimes (slightly more than 5% of the time) used Tohil slip clay. Clearly the production zones for San Juan and Tohil Plumbate were in close proximity to one another.
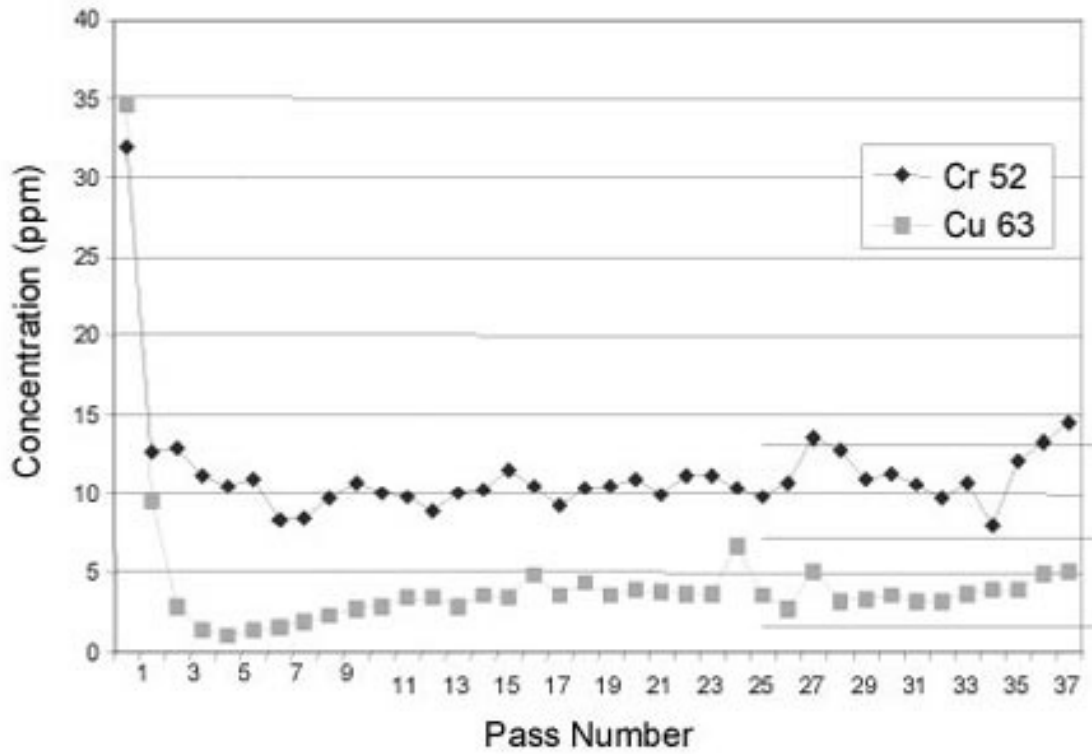
Figure 17: Copper and chromium concentrations in successive ablation passes over the same spot on shiny gray Tohil Plumbate specimen CPA1036.
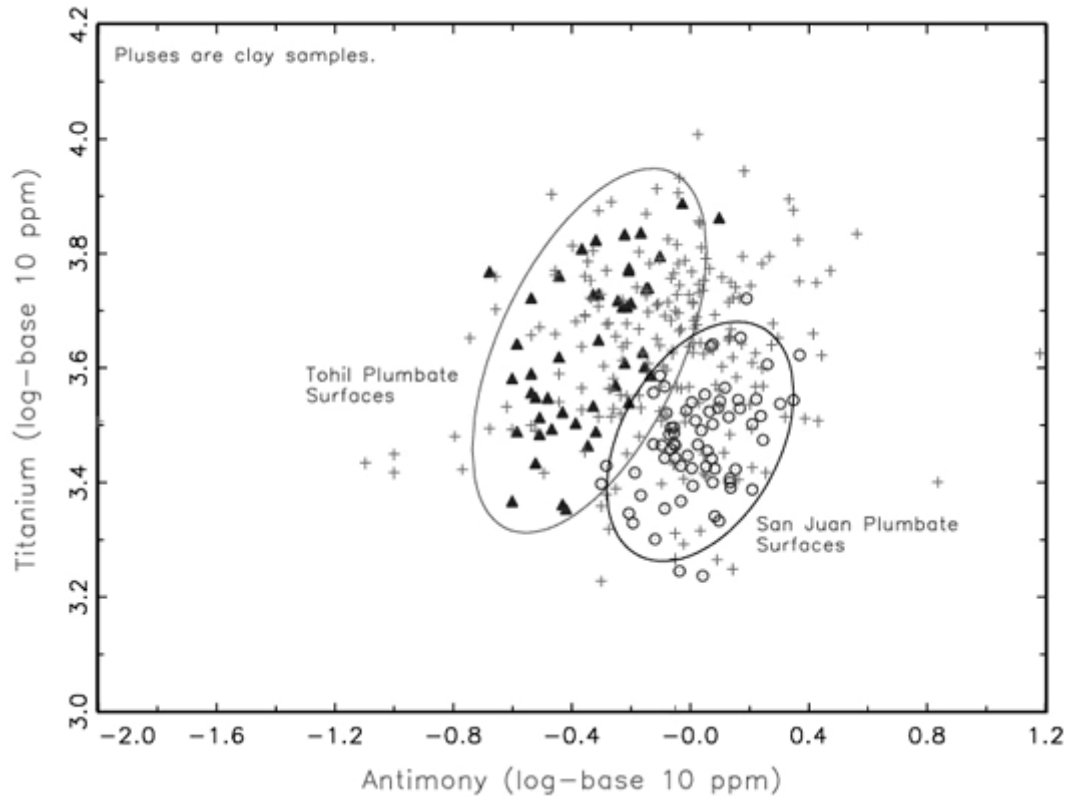
Figure 18: Bivariate plot of antimony and titanium log-concentrations in 145 Plumbate surfaces analyzed by LA-ICP-MS. Data obtained by LA-ICP-MS on clays from the Plumbate source region are shown as well.

TABLE 1
Frequencies of Plumbate compositional groups identified in paste data (INAA) and surface data (LA-ICP-MS)

		SURFACE:			
		Tohil	San Juan	Unassigned	Total
PASTE:	Tohil	40	2	9	51
	San Juan	3	59	17	79
	Unassigned	4	7	4	15
	Total	47	68	30	145

The fact that roughly the same chemical groups can be discerned in the surface data as in the paste data fits with the hypothesis that resource procurement zones for the slip

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material should correspond with procurement zones for the paste material. Alternatively, it is possible that San Juan and Tohil potters procured slip and paste clays from different production zones. Still another possibility is that processing and technological changes during firing so altered the composition of the slip that source clays cannot be identified. These hypotheses can be tested by the same method used to identify source zones for the two Plumbate paste compositional groups. That is, LA-ICP-MS data for the clays from the production region can be compared to the chemical profiles for the San Juan and Tohil groups identified in the surface data.

As before, elements were selected to use in the comparison partly based on whether they contributed to discrimination between the compositional groups. Thus, most transition metals were retained. However, since the depth profiling experiments demonstrated that certain elements, notably copper, chromium, and sodium were redistributed during the firing, these were excluded. In the end, source zone maps were generated using 21 elements, which are listed in the figure caption for Figure 19.

The source zone map for the San Juan group identified in the LA-ICP-MS surface data (Figure 19) coincides quite well with that for the paste data (Figure 12). On the surface data map, peak probabilities are along the eastern side of the Río Naranjo, south of the large site of La Blanca. The correspondence of the two San Juan source maps accords with the hypothesis that paste and slip raw materials for San Juan plumbate were procured from roughly the same area. One slight difference between the surface and paste maps is that the lower coast does not stand out on the surface map as it does on the paste map.

The Tohil surface data provenance map (Figure 20) also coincides with the Tohil paste data map (Figure 13). Again, this finding accords with the hypothesis that paste and slip materials were procured within roughly the same zone. As in the case of San Juan Plumbate, however, the lower-most coast does not stand out as clearly as a potential source on the map derived from surface data as it does on the map derived from paste data.
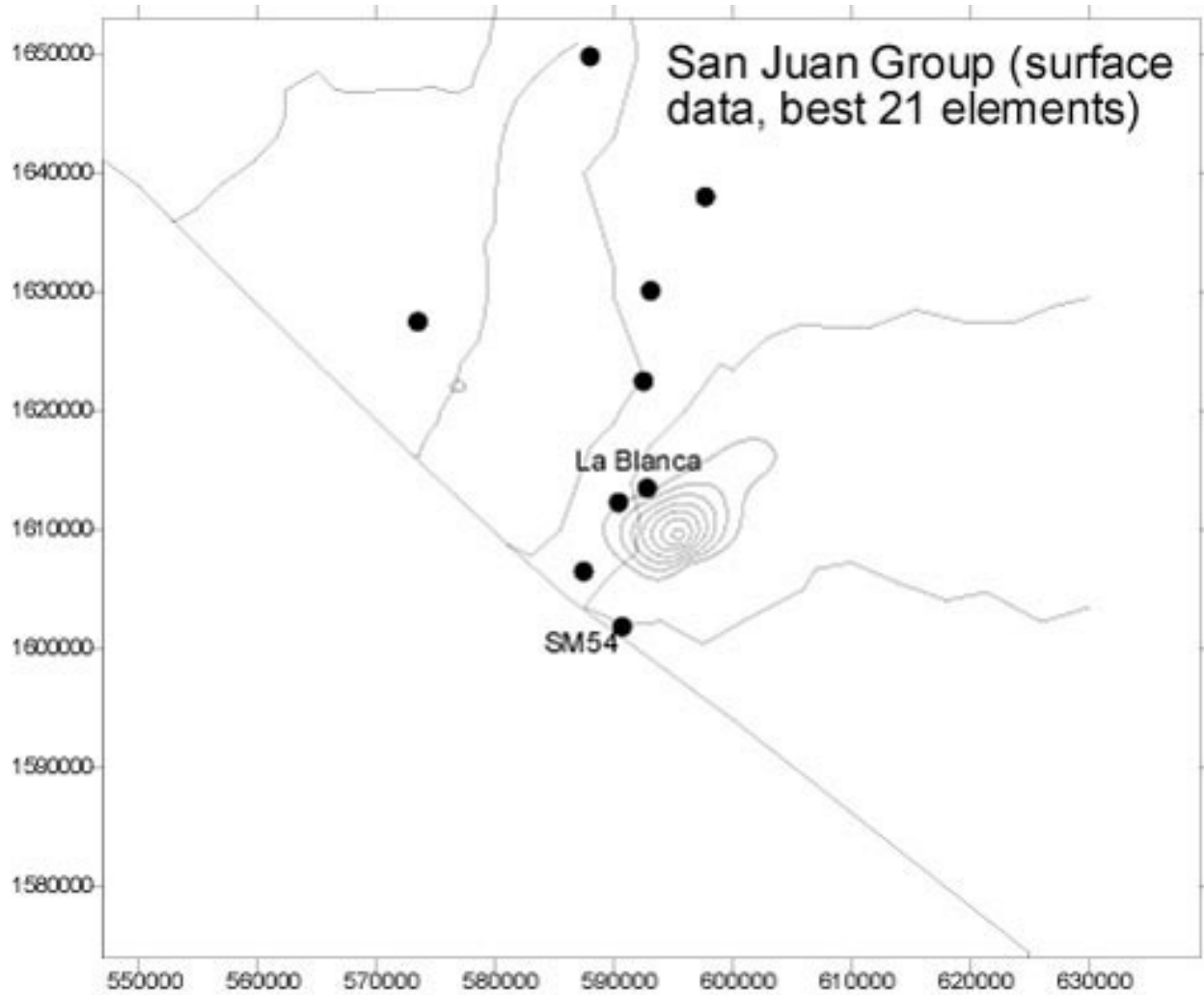
Figure 19: Source zone map for San Juan Plumbate based on comparison of LA-ICP-MS data for raw clays to the San Juan reference group identified in the LA-ICP-MS surface data. Elements used in the comparison are Al, Ca, Sc, ti, V, Fe, Ni, Co, Zn, As, Rb, Sr, Zr, Sb, Cs, La, Ce, Yb, Lu, Hf, Th, and U.
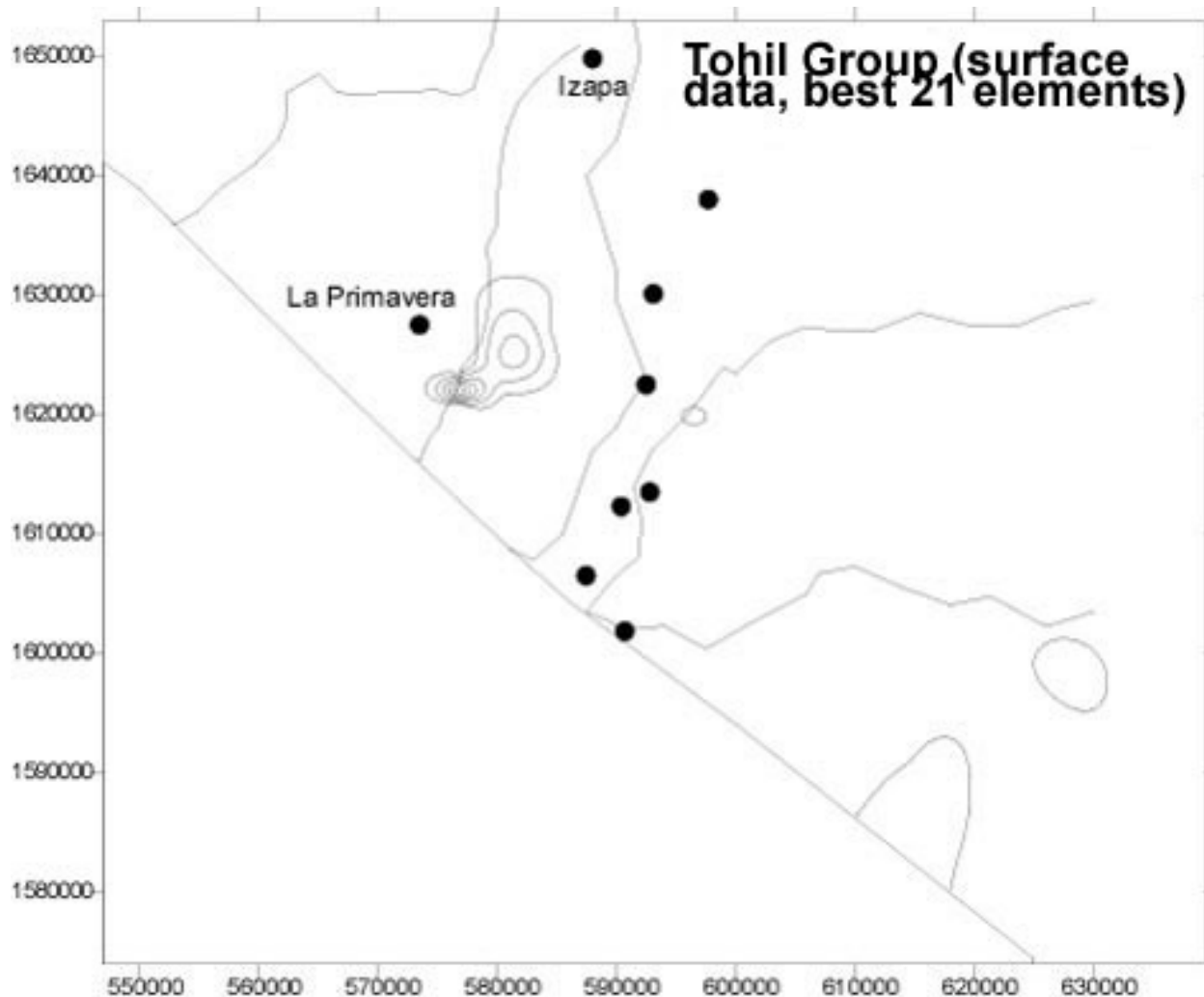
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Conclusion

It is interesting to compare the inferences drawn from the raw materials survey with other evidence regarding Plumbate source locations. Shook (1965:190) obviously was not too far wrong when he predicted, based on his archaeological observations, that the Plumbate sources would be found within a 20 km radius around the site of Santa Romelia (location shown on Figure 7). SM54, the littoral zone site where I found pottery-making by-products similar in composition to San Juan Plumbate (Neff and Bishop 1988), lies right on the peak of the San Juan probability surface estimated from paste data (Figure 12), although the surface data (Figure 19) indicate a source zone

further inland, near the major site of La Blanca. In this context, it is worth noting too that the late Edwin Shook (pers. comm. 1981; also cited in Veronda 1998) observed a feature he interpreted as a Plumbate kiln during road construction near La Blanca.

Bishop and I were also on the right track in suggesting that "in the vicinity of Izapa and La Primavera, potters eventually discovered the source of Tohil clay" (Neff and Bishop 1988:519). To be more precise, it is La Primavera, on the lower coast west of the Río Cahuacan, which probably lies within or near the Tohil source zone (Figure 20). Archaeological observations we made during the raw materials survey further reinforce this inference. In a zone about 8-10 km from the coast along the western side of the Río Cahuacan, there is a near-continuous scatter of Plumbate sherds visible on the surface in the banana fields. In some locations, excavations for drainage ditches in the bananas have obviously cut through dense subterranean deposits. Sherd scatters at these locations include very large Plumbate vessels, which certainly were not moved very far from where they were produced. This zone of dense Plumbate sherd scatters is on the probability peak for Tohil Plumbate surface raw materials shown in Figure 20. The combined evidence of provenance investigation and archaeological distribution thus leads to a highly specific inference about where Tohil Plumbate pottery was made.

The new provenance information presented here is consistent with the hypothesis that Plumbate production was a highly localized affair within the Chiapas-Guatemala border region. We have known for some time that Plumbate virtually swamps all other Late and Terminal Classic ceramics at sites all over this region (Coe and Flannery 1967; Love 1989; Lowe *et al.* 1982; Shook 1965). Now there can be little doubt that Plumbate's dominance reflects the strong economic ties that linked Late and Terminal Classic people living in different parts of the region. People at sites such as Izapa, El Sitio, Ayutla, Santa Romelia, and many others produced no Plumbate, but yet consumed Plumbate to the near exclusion of other ceramics. Meanwhile, potters within two localized zones on the lower coast, one near the mouth of the Río Naranjo and one near the mouth of the Río Cahuacan, specialized in producing Plumbate pots far in excess of what was needed to meet local demand. Perhaps it is not surprising that potters accustomed to intense economic interaction on a regional level eventually began to exploit opportunities available through interregional commerce, exporting Tohil Plumbate to Tula, Chichén Itzá, and other places in the Early Postclassic Mesoamerican world (Neff 1989b).

The results presented here provide a strong foundation for planning future archaeological fieldwork to recover information about Plumbate production facilities. Provenance investigation and archaeological observations clearly identify two specific locations, one along the Río Naranjo in Guatemala and one across the Mexican border, along the Río Cahuacan, as production zones for Plumbate pottery. A first phase of fieldwork would involve surface survey within these zones. Areas of high Plumbate sherd density would be identified and their boundaries determined. In a second phase, magnetometer surveys would be conducted within some or all of the high-density zones. The magnetometer surveys would identify magnetic anomalies, some of which, it can be hypothesized, would be baked clay features created by intense heat associated with firing of Plumbate pottery. In a third phase, excavations would be placed on and

around a sample of the magnetic anomalies. Associated with the archaeological surveys and excavations, detailed geomorphological survey and additional raw material sampling would be undertaken in order to provide a detailed local picture of the ceramic environment exploited by San Juan and Tohil Plumbate potters.

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