Petrographic evidence shows that pottery exchange between the Olmec and their neighbors was two-way

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Petrographic thin sections of pottery from five Formative Mexican archaeological sites show that exchanges of vessels between highland and lowland chiefly centers were reciprocal, or two-way. These analyses contradict recent claims that the Gulf Coast was the sole source of pottery carved with iconographic motifs. Those claims were based on neutron activation, which, by relying on chemical elements rather than actual minerals, has important limitations in its ability to identify nonlocal pottery from within large data sets. Petrography shows that the ceramics in question (and hence their carved motifs) have multiple origins and were widely traded.

chiefly trade | Formative Mexican archaeology | petrographic thin sections

An important process in Mexican prehistory was the rise of chiefdoms some 3,100–2,850 radiocarbon years ago, during the Early Formative period. As the leaders of these newly complex societies flexed their sociopolitical muscles, there was an escalation of trade in goods such as obsidian, marine shell, jade, iron ore, stingray spines, macaw feathers, and decorated pottery. Archaeologists have traced some of these items to their sources by using neutron activation, x-ray fluorescence, Mössbauer spectrum analysis, and other techniques.

Owing to their durability, ceramics are heavily relied on to document interregional contact. Although many pots were probably simply the containers in which chocolate, honey, fermented beverages, and other perishables were transported, the decoration on the vessels can provide clues to the region of origin.

Unfortunately, during the period 3100–2850 B.P., Mexico’s chiefdoms so often emulated each other’s best work that simple visual inspection of ceramics will not always confirm their place of origin. Four classes of widely circulated pottery, (i) pure white kaolinite ware, (ii) carved gray ware, (iii) incised white-slipped ware, and (iv) white-rimmed black ware, had multiple regional variants that are superficially indistinguishable. Thus, we need analyses that can link pottery to the bedrock geology of its homeland.

This paper focuses on pottery from the vicinity of five archaeological sites: Tlapacoya, in the Basin of Mexico; Moyotzingo, in the Valley of Puebla; Las Canoas, in the Tehuacán Valley; San José Mogote, in the Valley of Oaxaca; and San Lorenzo, in the Olmec region of the Gulf Coast (Fig. 1). These sites belonged to different chiefdoms and varied in altitude from near sea level at San Lorenzo to 2,250 m near Moyotzingo and Tlapacoya. The clays and tempers of each region have different geological origins. Tlapacoya lies among andesites and basalts. Moyotzingo sits below the lava and pumice deposits of Mt. Iztaccihuatl. San José Mogote’s geology features gneiss and volcanic tuff. San Lorenzo lies among sedimentaries (sandstone, lutite, and occasional limestone), and its pottery temper is mostly quartzitic or calcareous sand.

Previous Mineralogical Studies

Previous mineralogical analyses suggest that pottery moved freely among sites like Tlapacoya, San José Mogote, and San Lorenzo. For example, Williams (ref. 1, p. 30) found that a carved gray vessel from Tlapacoya contained sillar-type ignimbrite (tuff) of Oaxaca origin. Lambert (ref. 2, p. 262) found a Oaxaca-like combination of metamorphics and tuff in another vessel from Tlapacoya. Payne (ref. 2, p. 263) examined eight gray sherd from San Lorenzo whose carved motifs seemed more “Oaxaca-like” than “San Lorenzo-like.” One of the sherds could not be assigned a source, but four of the others were mineralogically identical to the Oaxaca pottery type Leandro Gray, and three more contained Oaxaca gneiss and volcanic glass. Payne (2) also examined a number of pure white kaolinite sherd found at San José Mogote. Some were tempered with local Oaxaca volcanic ash, but others seemed to be tempered with the quartzitic sand used at San Lorenzo. These kaolinite sherds were superficially indistinguishable, and all would have been assigned to the widespread type Xochitepec White.

This widespread circulation of pottery should surprise no one, because many other products followed the same routes. Obsidian from the Basin of Mexico reached Oaxaca and Veracruz; mollusk shells from both coasts reached the Basin of Mexico and Oaxaca; iron ore mirrors from Oaxaca reached Morelos and Veracruz (3). The bigger and more important a chiefly center, the more varied the gifts of foreign ceramics it was likely to receive.

Recent Neutron Activation Analysis

In 2002, Neff and Glascock (4) published an instrumental neutron activation analysis (INAA) of 944 potsherds from seven Mexican regions. Three years later, Blomster (5) joined them in an article on the implications of the study. Based on the INAA

Abbreviations: PTSA, petrographic thin-section analysis; INAA, instrumental neutron activation analysis; BNG, Blomster, Neff, and Glascock.

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results, Blomster, Neff, and Glascock (BNG) (5) concluded that the San Lorenzo Olmec “exported” pottery without receiving any in return. That pottery included Calzadas Carved, a gray ware with motifs whose iconography they believe disseminated “the social, political, and religious institutions of the Olmec.” BNG (ref. 5, p. 1071) even went so far as to claim that neighboring highland valleys did not exchange carved pots with each other.

Problems with Neutron Activation Analysis of Pottery

Here, we report the results of petrographic thin-section analyses (PTSAs) that show that many Formative chiefdoms, including the one headed by San Lorenzo, received carved gray ware from other regions. Before turning to those results, however, we must mention some problems inherent in INAA. Neutron activation does not identify the minerals in the pottery; it identifies only the chemical elements, and those elements can occur in many different types of parent rock. Although INAA works well on single-source rocks, such as obsidian, it works less well on ceramics. Pottery is a human artifact whose chemicals derive 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. Because it identifies minerals, PTSA can link the sherd to the bedrock geology from which the clay or temper came; INAA, by contrast, cannot distinguish among the five sources that contributed the elements recorded.

The result is that PTSA sometimes overturns the results of INAA. A recent example comes from Pinson Mounds, TN, a large site of the Middle Woodland period. Excavator R. Mainfort asked Neff and Glascock (6) to neutron-activate 117 Pinson sherd, 19 of which were considered trade wares based on stylistic attributes. The INAA results were said to show “conclusively” that all sherds (including the suspicious 19) were “produced locally” (ref. 6, p. 65). Unconvinced, Mainfort asked Stoltman (7) to perform PTSA on 52 sherd from Pinson and other sites, including 39 of those used in INAA. PTSA indicated that at least nine of the specimens “likely were nonlocal products,” based in part on exotic mineral tempers that do not occur within 50 km of Pinson (7).

Stoltman and Mainfort (ref. 7, p. 19) concluded that INAA has “important limitations” in its ability to reliably identify individual nonlocal sherds from within large data sets, underestimating both diagenesis and vessel use. (Consider, as one example, what the Mexican custom of soaking maize in lime water might do to a pot’s calcium levels.)

Nowhere are the limitations of INAA more evident than in Neff and Glascock’s (ref. 4, p. 10) acknowledgment of “a troublesome similarity between certain gray ware pottery from the Valley of Oaxaca and pottery in the San Lorenzo reference group,” a similarity they label “remarkable considering the geographical separation of several hundred km.” In contrast to INAA, petrographic analysis easily separates the two groups, because the “Oaxaca Gris-1” vessels feature gneiss and volcanic tuff (Fig. 2A), whereas the Olmec-area vessels are tempered with fine quartzitic or calcareous sand (Fig. 2B). The fact that INAA had difficulty separating them shows that reliance on chemical elements is not the best way to trace individual sherds to their source. “Pots,” as recent critics of INAA point out, “are not rocks” (ref. 8, p. 409).

Many archaeologists also have reservations about Neff and Glascock’s (5) practice of finalizing their INAA analysis by

Table 1. Results from discriminant function analysis (DFA) of all 944 ceramic samples

<table>
<thead>
<tr>
<th>Archaeological context</th>
<th>Source region as identified by DFA</th>
<th>Percentage locally produced</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) San Lorenzo</td>
<td>234 0 1 21 2 2 1 251 89</td>
<td></td>
</tr>
<tr>
<td>2) Mazatán</td>
<td>14 234 3 10 0 0 0 1 262 89</td>
<td></td>
</tr>
<tr>
<td>3) Valley of Oaxaca</td>
<td>7 0 45 20 1 0 6 79 57</td>
<td></td>
</tr>
<tr>
<td>4) Etlatongo</td>
<td>7 0 3 57 1 0 0 68 84</td>
<td></td>
</tr>
<tr>
<td>5) Tlapacoya</td>
<td>3 0 0 106 0 0 129 82</td>
<td></td>
</tr>
<tr>
<td>6) San Isidro</td>
<td>1 0 0 46 0 0 50 92</td>
<td></td>
</tr>
<tr>
<td>7) Tehuantepec</td>
<td>5 0 4 3 0 93 105 89</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>261 234 56 134 110 48 101 944 85</td>
<td></td>
</tr>
<tr>
<td>Percentage exported</td>
<td>14.2 19.6 57.5 3.6 4.2 7.9 14.7</td>
<td></td>
</tr>
</tbody>
</table>

Fig. 2. Petrographic thin sections easily distinguish Oaxaca gray ware of the Gris-1 group from pottery of the San Lorenzo region, despite their “troublesome similarity” when analyzed by neutron activation (ref. 4, p. 10). (A) A type G12 sherd from Monte Albán, Oaxaca, contains gneiss minerals and volcanic glass. (B) A Perdida Black-and-White sherd from the Olmec region is tempered with fine quartzitic and calcareous sand. These thin sections (and all others) were photographed at ×10 magnification. The large quartz grain near the center of A is 1 mm in maximum length. Plane-polarized light was used in A and B.
calculating Mahalanobis distances. The use of this statistic may cause 26–30% of the sampled sherds to be dismissed as “unassigned” or “outliers,” converting an “amorphous shotgun-blast data array” into confidence ellipses that may simply be an artifact of the method (7). At least five of the imported vessels in the Pinson study had been dismissed as unassigned or outlier. In the BNG study of Mexican pottery, no fewer than 48 sherds from San Lorenzo (any one of which could have been foreign) were listed as unassigned.

### Discriminant Function Analysis

In table 2 of the supporting information in ref. 5, BNG list 944 potsherds used in their analysis. The chemical elements detected in each sherd also are given.¶ Also mentioned is a “reference collection,” but no details, counts, or chemical elements for this collection are given (4, 5).

When alternative approaches are used to analyze the results of INAA, the outcome can be different, especially if the undescribed reference collection is excluded and no sherds are unassigned. To test this possibility, Moyle subjected the INAA data for all sherds included in table 2 of the supporting information in ref. 5 to a discriminant function analysis. This design tests the hypothesis that archaeological context correctly describes the place of origin of a sherd. Moyle’s first analysis incorporated all 944 sherds, including those considered unassigned by BNG (Table 1). Moyle’s second analysis covered only those 756 sherds assigned to a source by BNG (Table 2). Both analyses used a linear discriminant model, complete estimation, and logarithm base 10 transformed data (using \( x + 1 \) to accommodate zero values).

As Flannery et al. (9) show in the companion paper to this article, Blomster’s (5) sampling of archaeological sites was highly biased (i.e., noncomparable from region to region). In regions such as San Lorenzo (Veracruz) and Mazatán (Chiapas), on the one hand, he collected hundreds of sherds of undecorated utilitarian wares and fewer carved gray wares. In regions such as Tlapacoya (Basin of Mexico) and the Valley of Oaxaca, on the other hand, he collected mainly carved gray and kaolin white sherds, which looked as if they could have come from San Lorenzo. Such sampling inevitably biases the outcome in such a way that the San Lorenzo and Mazatán collections are likely to include a higher percentage of local vessels, whereas the Tlapacoya and Valley of Oaxaca collections are likely to include a higher percentage of exotic vessels.

Despite this sampling bias, discriminant function analysis reveals that most of the pottery found in each region was locally

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¶Elements used include Al, As, Ba, Ca, Cs, Co, Cr, Cs, Dy, Eu, Fe, Hf, K, La, Lu, Mn, Na, Nd, Ni, Rb, Sb, Sc, Sm, Sr, Ta, Tb, Th, Ti, U, V, Yb, Zn, and Zr. These were recorded in parts per million for each sherd.

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**Fig. 3.** Thin sections of sherds recovered from San José Mogote. Sherds shown are Leandro Gray (A), Delfina Fine Gray (B), and Calzadas Carved (C). Leandro Gray contains gneiss minerals and volcanic glass; Delfina Fine Gray is similar but finer grained; Calzadas Carved is tempered with fine quartz sand. All of these sections were photographed under cross-polarized light, which, in A and B, highlights the twinned feldspars that are so characteristic of pottery tempered with Valley of Oaxaca gneiss.
made, that pottery judged to have originated in any one of the
six regions other than Mazatán was found in at least one other
region, and that most regions received pottery from several other
areas. Table 1, in which no sherds have been unassigned, shows
San Lorenzo receiving pottery from Oaxaca, Etlatongo, Tlapa-
coya, Tehuantepec, and San Isidro. The Valley of Oaxaca
received pottery from San Lorenzo, Etlatongo, Tlapacoya, and
Tehuantepec; Etlatongo received pottery from San Lorenzo, the
Valley of Oaxaca, and Tlapacoya; and so on.

Table 2, from which all of BNG’s unassigned sherds have been
omitted, understandably shows fewer exchanges of pottery be-
tween regions. Despite this, the results continue to show that
pottery was exchanged among highland valleys and between the
highlands and lowlands. Table 2 also makes clear the extent to
which having a large unassigned category suppresses evidence
for interregional exchange.

Interestingly, both tables show Etlatongo exporting a higher
percentage of its pottery than San Lorenzo. Whether this
situation (i) results from sampling bias or (ii) reflects the
importance of the Etlatongo region’s known kaolinite sources
(figure 2.2e in ref. 3) remains to be determined.

Petrographic Analyses
Having discussed both the problems of INAA and the alternate
ways its results can be analyzed, let us now turn to petrographic
thin-section analysis.

In 2005, Marcus and Flannery supplied Stoltman with a series
of sherds (all from different vessels) from the five Mexican sites
listed in the Introduction. About half of the samples had
previously been singled out as possible trade pieces. Although
Marcus and Flannery knew the provenience of all sherds,
Stoltman treated all but a few reference specimens as “blind
samples,” as he had in the case of the Pinson Mounds. Only at
the end of his petrographic study did Stoltman learn the prove-
nience and typology of all sherds.

Mineralogical contrasts were striking. The temper in most Oax-
aca vessels (six from San José Mogote and one from nearby Monte
Albán) was gneiss-derived grit, including both plagioclase and
microcline (twinned feldspars) as well as polycrystalline quartz,
amphiboles, mica, and epidote. Volcanic glass, almost certainly a
natural inclusion in the local clays, was also present in the matrix of
these sherds (Figs. 2A and 3A and B). One “local” specimen from
the San Lorenzo area available for this study (Perdida Black-and-
White) was tempered with fine sand, 35% of which was calcareous
(Fig. 2B). One carved sherd found at San José Mogote (blind
sample 51-40 in Stoltman’s catalog) was sparsely tempered with fine
quartz sand and is interpreted here as a trade vessel of Calzadas
Carved from the Olmec area (Fig. 3C).

Two other sherds from San José Mogote (blind samples 51-28
and 51-31), originally considered to be Delfina Fine Gray, have
a distinctive gray paste generously sprinkled with laminar, opaque
alteration products that are believed to have been derived from
micas. The predominant crystalline mineral in these vessels is
quartz, which, although usually fine-grained, is characteristically
polycrystalline and strained, indicative of metamorphic alteration.
The source of this distinctive paste is unknown, but it almost
certainly derives from altered bedrock in the highlands. What is
especially interesting about these two sherds is that an identical
specimen (blind sample 51-34) was recovered at San Lorenzo,
where it was originally assigned to Calzadas Carved (see below). We
believe that this vessel may have been imported to San Lorenzo
from somewhere in the highlands.

Included in Stoltman’s blind samples were six of the eight
“Oaxaca-like” sherds from San Lorenzo that Payne (2) had exam-
ined earlier. Two of the original eight, labeled SL-P-1c-X and
SL-B4-9-SUR, had been totally used up by Payne (2). One of the

Fig. 4. Thin sections of sherds from traded carved gray wares. Sherds in A and B, containing gneiss minerals and volcanic glass, are Leandro Gray vessels from Oaxaca exported to San Lorenzo. (A was labeled SL-RNW-St-1p@, and B was labeled SL-NW-M1-2c). C is a Leandro Gray sherd from a Oaxaca vessel exported to Moyotzingo, Puebla. D, containing andesite porphyry, is a section of Tortuga Polished vessel exported from Tlapacoya, Basin of Mexico, to San José Mogote, Oaxaca. A–C were photographed under cross-polarized light. D was photographed under plane-polarized light.
remaining six sherds, SL-B4-9-EC, was blind sample 51-34, discussed above, whose paste was identical to 51-28 and 51-31. The five remaining sherds from San Lorenzo (SL-NW-M1-2c, SL-P-6e, SL-RNW-St-1p0, SN-PNW-I-I1, and TE-R-72-G), however, were all clearly Leandro Gray from Oaxaca, combining distinctive gneiss minerals and volcanic glass that are not present at San Lorenzo (Fig. 4 A and B). In the case of the six remaining sherds, therefore, their Oaxaca-like stylistic attributes correctly identified them as foreign to San Lorenzo.

Clearly, exchanges of pottery between the Olmec and their highland neighbors were reciprocal. Leandro Gray vessels from Oaxaca reached San Lorenzo, where some were confused with the local type Calzadas Carved. Calzadas Carved vessels from San Lorenzo reached Oaxaca, where at least one was confused with the local type Delfina Fine Gray. There were two reasons for the confusion: (i) the carved gray wares look superficially similar even when not eroded and (ii) many sherds from San Lorenzo show “appallingly bad” erosion (ref. 10, p. 131).

Stoltman also examined other blind samples from San José Mogote, Tlapacoya, Las Canoas, and Moyotzingo. One carved gray sherd from Tlapacoya (11) and another from Moyotzingo (12), both Oaxaca-like in appearance, turned out to be Leandro Gray from Oaxaca (Fig. 4 C). One carved gray sherd from San José Mogote, considered by C. Niederberger (11) to be Tortuga Polished from Tlapacoya, turned out to contain Tlapacoya’s distinctive andesite porphyry; its ground mass was dominated by fine-grained plagioclase and glass with phenocrysts of plag, amphibole, and pyroxene (Fig. 4 D). The sherd from Las Canoas (figure 12.141 in ref. 2), superficially resembling both Delfina Fine Gray and Calzadas Carved, turned out to be from neither Oaxaca nor San Lorenzo. It had a unique, strongly vitrified paste with sparse inclusions (amphiboles, epidote, zircon, and plagioclase) and virtually no quartz. Taken in combination with blind samples 51-28 and 51-31, the Las Canoas sherd suggests that several highland regions were producing carved wares superficially similar to Delfina Fine Gray.

Two sherds of Xochiltepec White, a widespread kaolin ware for which Payne (2) had already detected several regional variants, were also included among the PTSA samples. Both of these sherds were recovered at San José Mogote in Oaxaca, where kaolinite can be obtained from thermal vents in altered ignimbrite. The temper in the two vessels was distinct: volcanic ash in one case (Fig. 5 A) and fine quartz sand in a high-silt (16%) paste in the other (Fig. 5 B). The former is presumed to be of local origin, whereas the latter would appear to be intrusive from the Olmec area. Future petrography will almost certainly reveal other regions producing Xochiltepec White, because many more kaolin sources are known throughout central Mexico.

A Hollow, White-Slipped “Baby Doll”

A sherd from one of San José Mogote’s oldest known hollow, white-slipped baby doll figurines was given to Stoltman as blind sample 51-41. The fragment came from Feature 65, dating to perhaps 3200 radiocarbon years B.P. (ref. 3, p. 307). The Olmec are frequently given credit for these figurines, even though the majority of published specimens come from the Mexican highlands. PTSA, however, confirms that Oaxaca’s earliest baby dolls were of local manufacture, because the fragment from Feature 65 contained the same combination of gneiss minerals and volcanic glass as the local Oaxaca pottery type Atoyac Yellow-White (Fig. 5 C).

Conclusions

Petrographic analysis shows that exchanges of pottery among early Mexican chiefdoms were widespread and reciprocal. Leandro Gray ware from Oaxaca reached the Olmec region, the Basin of Mexico, and the Valley of Puebla. Both Tortuga Polished ware from the Basin of Mexico and Calzadas Carved ware from the Olmec region reached Oaxaca. Two of the most widely distributed classes of pottery, pure white kaolin ware and carved gray ware, seem to have been produced in more regions than previously realized, making it impossible to attribute them exclusively to the Olmec. It should also be borne in mind that hundreds of other archaeological sites, which may have been intermediaries in this early exchange system, have yet to be excavated. In retrospect, having 10 sherds each from 90 places would be better than having 900 sherds from only 10 places.

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