Copper Sources, Metal Production, and Metals Trade in Late Postclassic Mesoamerica

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Copper ore sources exploited during the Late Postclassic Period (1300 to 1521 A.D.) were located by means of lead isotope analyses of copper ores from 15 deposits in West Mexico, Oaxaca, and Veracruz and of 171 copper artifacts from nine Mesoamerican archaeological sites in West Mexico and in southern, central, and northeastern Mesoamerica. West Mexican ores provided copper metal for most artifacts from the west Mexican settlements of Atoyac and Urichu, as well as for some artifacts from Aztec towns, Huastec centers, a Maya site, and settlements in Oaxaca and Chiapas. West Mexico was not marginal to Mesoamerican events but played the primary role in the production and distribution of copper and bronze artifacts, one of Mesoamerica's key exotic goods.

Metal artifacts first appeared in Mesoamerica in the west around 650 A.D. Metallurgy was introduced from South America by a maritime route. West Mexico contains the most varied array of ore minerals available to ancient Mesoamerican smiths, including copper carbonates and sulfides, arsenopyrite, argentite, and silver sulfosalts. Cassiterite, the tin oxide ore, occurs in a southwestern extension of Mexico's Zacatecas tin province. West Mexican metalworkers focused primarily on fashioning ritual and sacred objects throughout the 900-year history of this technology. Before 1200 A.D., they used copper, principally for bells but also for small cold-worked implements. After 1200 to 1300 A.D., they produced copper-arsenic bronze, copper-tin bronze, and copper-silver alloys, not only for their golden and silvery colors but also to optimize the design and functionality of objects previously made in copper. Bells and elaborate tweezers as well as needles, awls, and other tools from this time appear at other Mesoamerican sites (*1–4*). Here, we present lead isotope data that demonstrate that many of these artifacts were produced in the west Mexican region.

Geochemical and Archaeological Context

Lead isotope (LI) analyses can be used to identify ore sources for artifacts made from copper and copper alloys (*5*) by matching the isotopic signatures of ore lead to those of the artifacts. The isotopic composition of ore lead is a function of the age and chemistry of the source rocks. Lead is present at analyzable concentrations in all copper artifacts. Because LI compositions are not altered during ore smelting, they provide a means of identifying the ore sources for the artifact metal. We followed the geological convention of plotting $^{208}Pb/^{204}Pb$ versus $^{206}Pb/^{204}Pb$ in creating LI fields (*6*). We omitted $^{207}Pb/^{204}Pb$ from the plots because these values vary only slightly in our samples, as expected with ores related to Mesozoic and younger magmatism, and add little information.

LI data are most effective in excluding certain deposits as likely source areas. Positive source identification is more difficult because not all deposits can be sampled. The level of confidence in identifying sources depends on whether regional geologic formation processes have resulted in clearly delineated LI fields, as well as on the number of deposits analyzed. We considered a deposit or mining region to qualify as a potential source when the artifact signature fell within the ore field. To determine whether the deposit could have been exploited by ancient Mesoamerican metalworkers, we evaluated its physical characteristics (size, accessibility, associated archaeological remains), regional archaeology, and historical evidence for mining. The design and composition of the artifact allowed us to narrow possible sources further. Where artifact designs and compositional types concentrate in particular geographical areas, we assumed that these objects may have been produced in or near those areas (*7*). Where artifact fields overlap, we used such information to determine which deposit or region constituted the more plausible metal source.

We analyzed 121 ore samples (*8*) from 15 copper deposits in Jalisco, Michoacan, Veracruz, and Oaxaca (Table 1) (*9*). Jalisco and Michoacan lie in the heart of the west Mexican metalworking zone. Ores in Veracruz and Oaxaca (Fig. 1) provided geographical breadth. Moreover, both regions supported state-level societies in the pre-Hispanic era, and copper artifacts have been excavated in or near both. Also, in Oaxaca, a local copper-gold alloy casting technology developed after 1200 A.D.; its relation to West Mexico's earlier copper-based metallurgy is unclear.

The ore isotopic fields (Fig. 2) are typical of continental arc deposits, plotting near the Stacey-Kramers reference line (*10*). The data used to construct some fields in Fig. 2 [Autlán, Ayutla, Oaxaca (Los Ocotes and El Taviche), and Veracruz (the Las Minas deposits)] represent groupings of individual mines in each area to simplify the

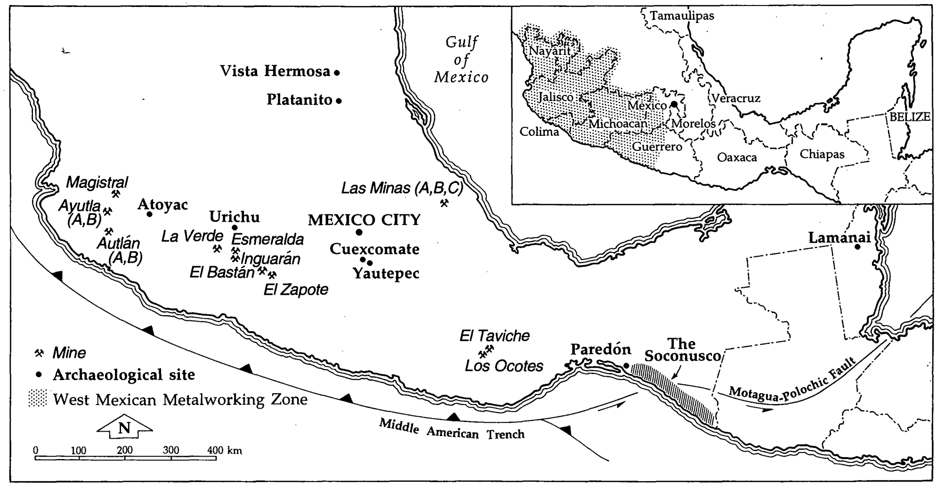

Fig. 1. Mesoamerican copper mines and archaeological sites.

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plots. Most ore data are distributed fairly evenly within their fields except for the Inguarán and Bastán data, which are concentrated in the upper halves of the fields. Cumming *et al.* (*11*) observed a trend in Mexican ores toward higher LI ratios with increasing distance from the Middle American Trench (Fig. 1), which they attributed to increasing contributions of crustal lead. Most of our data support this simple trend [compare Ayutla and Magistral in Jalisco to Veracruz (Las Minas)]. However, between 75 and 40 million years ago (Ma), the distance between southwestern Mexico and the trench was greatly reduced as a result of the southeasterly movement of much of Honduras and Nicaragua along the Montagua-Polochic fault zone (*12*). Thus, deposits that deviate from the trend and are likely characterized by higher LI ratios could exist in the study areas. Two Michoacan deposits, La Verde and Esmeralda, show anomalously high and variable $^{206}Pb/^{204}Pb$ ratios (Fig. 3). These values can be explained only by incorporation of large amounts of lead from near-surface sedimentary rocks.

We measured LI ratios and chemical compositions of 171 copper artifacts (9) from the nine archaeological sites shown in Fig. 1. These sites were selected for proximity to copper deposits or because the sites are located in Mesoamerican regions where complex, culturally distinct societies developed. Atoyac and Urichu were settlements in the west Mexican metalworking zone; Yautepec and Cuexcomate were Aztec towns; Mixe-Zoque–speaking peoples lived in the Paredón (Oaxaca) and Soconusco regions; and Lamanai (Belize) was Maya. Huastec peoples inhabited Platanito and Vista Hermosa. Artifacts date from 1400 A.D. to the Spanish invasion in 1521, although dates for some may be slightly earlier. Artifacts whose chemical compositions (9) indicate that the metal was derived from copper-lead or copper-silver alloys or from remelted metal (*13*) were excluded from the plots and Tables 2 through 6.

Table 1. Mineralogy of samples analyzed. Minerals at each mine are listed in order of relative abundance. Mineral codes: py, pyrite; cpy, chalcopyrite; hem, hematite; goet, goethite; cup, cuprite; po, pyrrhotite; mo, molybdenum; bn, bornite.

State	Mine	Mineral
Jalisco	Autlán A	py, cpy, Cu carbonate, hem
	Autlán B	Cu carbonate, goet, cup
	Ayutla A	py, cpy, whole rock
	Ayutla B	py, Cu carbonate, Fe oxide
	Magistral	Cu carbonate, goet
Michoacan	El Bastán	py, cpy, po, mo
	Esmeralda	py, cpy
	Inguarán	py, cpy
	El Zapote	Cu carbonate, Cu silicate
	La Verde	bn, py, cpy, mo, Cu carbonate, Cu silicate
Oaxaca	Los Ocotes	py, cpy
	El Taviche	py, cpy, Cu carbonate
Veracruz	Las Minas A	py, cpy, Cu carbonate
	Las Minas B	py, cpy, Cu carbonate
	Las Minas C	py, cpy, Cu carbonate

Sources for West Mexican Metalworking Zone Artifact Copper

Two hundred metal artifacts were excavated from burials and houses at Atoyac, a large settlement located in Jalisco's Sayula basin. Atoyac was inhabited by local peoples until around 1450 A.D., when neighboring Tarascan groups either invaded or colonized (*14*). The artifacts date to 1450 or later. Some 80% are status items (bells, tweezers, and rings), although utilitarian objects such as sewing needles also were recovered. We carried out LI studies of 35 artifacts (9).

Urichu was one of eight Tarascan administrative centers. The Tarascans, whose capital Tzintzuntzan was in Michoacan, were the most powerful Late Postclassic political entity in Mesoamerica apart from the Aztec. Excavations of Urichu burials (*15*) produced 19 metal artifacts, including rings, a tweezer, needles, and awls; seven could be analyzed (9).

LI ratios for the Atoyac and Urichu artifacts fall within Michoacan's Inguarán and Bastán fields and Jalisco's Ayutla, Autlán, and Magistral fields (Fig. 4). A few ratios lie in the Oaxaca and Zapote field,

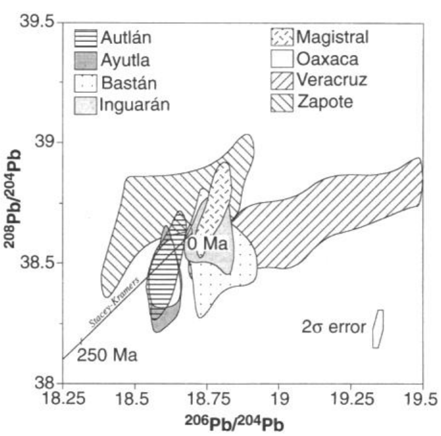

Fig. 2. LI ratios of Mexican ores represented as fields. Fields include the 95% error envelopes of all data.

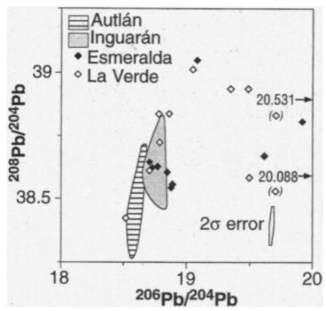

Fig. 3. Anomalously high and variable $^{206}Pb/^{204}Pb$ of Esmeralda and La Verde ores compared with typical Jalisco (Autlán) and Michoacan (Inguarán) ore fields.

and a few also fit with the Esmeralda and La Verde mines (Figs. 2 and 3) (9). We can eliminate some sources on the basis of historical and other evidence. Neither Zapote nor Esmeralda were exploited by ancient miners; both are small, recent prospects. The probability is also low that Magistral was mined before the Spanish invasion. A surface survey showed no evidence for pre-Hispanic exploitation, and copper artifacts are rarely reported from the area. Only two of the highly variable La Verde ore samples could have constituted parent material for these artifacts, although La Verde cannot be discounted entirely as a possible source (*16*). The likelihood that Oaxaca could have provided metal (or artifacts) to Urichu or Atoyac is low, because the artifacts in question—several Atoyac copper-tin bronze bells and a copper ring—are well documented west Mexican metalworking zone types in design and composition (*1, 4, 17*).

These LI data, coupled with historical and archaeological evidence, indicate that Inguarán, Bastán, and mines in the Ayutla and Autlán regions constitute the most probable sources for Atoyac and Urichu

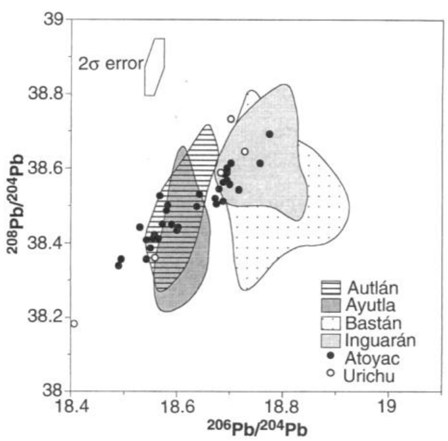

Fig. 4. LI ratios of artifacts from Atoyac and Urichu, plotted against ore deposit fields of Ayutla and Autlán (Jalisco) and Inguarán and Bastán (Michoacan).

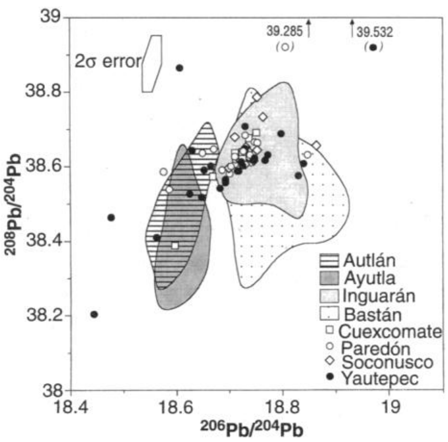

Fig. 5. LI ratios of artifacts from Cuexcomate, Paredón, the Soconusco, and Yautepec. Ore fields are as in Fig. 4.

artifacts. Sixteenth-century documents report preconquest mining at Inguarán (*1*, *4*, *18*), one of Mexico's largest copper mines. Bastán, currently under exploitation, lies in a region where copper-based artifacts frequently appear. Moreover, local people report archaeological remains including vitrified material nearby, which suggests that smelting may have been carried out there.

Jalisco's Ayutla and Autlán regions are currently classified as mining districts (*19*) and were active at the time of the Spanish invasion in 1521. The 16th-century *Relaciones Geográficas*, a compilation of responses to a Spanish questionnaire about the political geography and resources of the conquered territories, describes copper and silver deposits near Ayutla (*20*). Also, copper artifacts have been recovered in the Ayutla area. Autlán was "a large town," according to conquest-period observers. They reported copper and gold mines in the vicinity. Archaeological deposits containing Autlán pottery sometimes contain copper artifacts (*21*), and Autlán copper artifacts appear in museum collections.

Table 2. Atoyac (A) and Urichu (U) probable ore source fields by artifact type, number, and composition.

Artifact	Number of artifacts					
	Jalisco		Michoacan		Unknown	
	A	U	A	U	A	U
Bells						
Cu	2	–	–	–	–	–
Cu-As	1	–	2	–	–	–
Cu-Sn	3	–	–	–	–	–
Tweezers						
Cu-As	–	–	–	–	2	–
Cu-Sn	–	–	3	–	–	–
Rings						
Cu	1	–	–	–	1	–
Cu-Sn	1	1	1	1	–	2
Needles						
Cu	3	–	1	–	–	–
Cu-As	2	–	5	–	–	–
Cu-Sn	–	–	1	–	2	–
Tools						
Cu-As	–	–	–	1	–	–

Thus, Jalisco ores (from mines in the Ayutla and Autlán regions) provided metal for some Atoyac bells, rings, and needles made from copper and for their copper-tin and copper-arsenic bronze counterparts (Table 2). Michoacan ores (Inguarán and Bastán) provided metal for other Atoyac bronze bells, rings, and needles, and also for tweezers. Metal for some artifacts comes from unidentified sources. Ores from both Jalisco and Michoacan also provided metal for Urichu objects (Table 2), which are made from copper-tin and copper-arsenic bronze. Two Urichu artifacts were made from metal smelted from ores whose sources we cannot identify. The most noteworthy implications of these data are that (i) Jalisco and Michoacan are distinct metal-production areas and lie within the domain of distinct ethnic and cultural groups: peoples living in the Autlán and Ayutla areas, and the Tarascans in Michoacan; and (ii) copper-arsenic and copper-tin bronze metal was produced in at least two areas of the west Mexican metalworking zone.

Sources for Central, Southern, and Northeastern Mesoamerican Artifact Copper

LI ratios for many artifacts recovered outside of the metalworking zone point to west Mexican ores as sources. The sites are located in Morelos, Oaxaca, Chiapas, Tamaulipas, and Belize (Fig. 1). These LI data are reinforced by artifact design and composition, which in all but a few cases conform to the west Mexican pattern (*1*–*4*).

Yautepec and Cuexcomate, two Aztec towns in Morelos, lie to the east of the metalworking zone. Morelos contains few copper deposits. Yautepec (1300 A.D.–Spanish invasion) excavations produced 31 metal artifacts from well-dated midden deposits associated with domestic urban houses. We analyzed 25 of these artifacts. Most were needles, although a few were religious and status items such as bells and tweezers. Yautepec objects are made primarily from copper-tin and copper-arsenic bronze and alloys of copper-arsenic-tin (*9*). LI ratios place most of these within the Michoacan (Inguarán) field; the remainder fall within the Jalisco field or come from unidentified sources (Fig. 5 and Table 3). Cuexcomate excavations (*22*) produced 45 metal artifacts, predominantly needles and awls, again reflecting the domestic excavation contexts. The eight items available for analysis all date to after 1430 A.D. The LI ratios (*9*) of these artifacts place them within the Inguarán-Bastán (Michoacan) fields, except for a copper-tin bronze needle that has a Jalisco signature (Fig. 5 and Table 3). These LI data indicate that Aztec peoples in Yautepec and Cuexcomate acquired metal objects made in Tarascan territory and in Jalisco. Zinapecuaro obsidian, a source under Tarascan control, occurs at Late Postclassic Morelos sites, furnishing other evidence for Aztec-Tarascan exchange (*23*).

We also analyzed artifacts from Paredón, on the Gulf of Tehuantepec in Oaxaca, and from several sites in the Soconusco region (Fig. 1). Informal excavations at Paredón, a coastal settlement consisting of mounds scattered over an area of several square kilometers, have yielded hundreds of metal artifacts, including bells, tweezers, needles, and sheet metal items known as axe-monies. These artifacts have been recovered eroding out of mounds and can be dated to after 1350 A.D. on the basis of their association with Late Postclassic pottery. We analyzed 24 artifacts, primarily needles and sheet metal fragments (*9*). As Fig. 5 shows, most match the Inguarán-Bastán fields. Of these, a bell, a tweezer, and needles made from copper-tin bronze and copper-arsenic-tin alloys (Table 4) are similar in design and composition to Michoacan counterparts. The axe-money variety recovered at Paredón (*24*) appears most frequently in Michoacan and Guerrero and only sporadically in Jalisco. The Paredón sheet metal items (Table 4) probably represent axe-monies of

Table 3. Yautepec (Y) and Cuexcomate (C) probable ore source fields by artifact type, number, and composition.

Artifact	Number of artifacts					
	Jalisco		Michoacan		Unknown	
	Y	C	Y	C	Y	C
Bells						
Cu-As	–	–	–	1	–	–
Cu-Sn	–	–	1	–	–	–
Tweezers						
Cu-Sn	–	–	–	1	–	–
Cu-As-Sn	–	–	1	–	–	–
Sheet						
Cu-As	–	–	1	–	–	–
Cu-Sn	–	–	–	–	1	–
Needles						
Cu	4	–	3	2	2	–
Cu-As	2	–	4	–	–	–
Cu-Sn	–	1	–	–	–	–
Cu-As-Sn	–	–	2	–	1	–
Tools						
Cu	–	–	1	–	–	–
Cu-Sn	–	–	–	1	–	–
Cu-As-Sn	–	–	1	–	–	–

the same type. Three artifacts match Jalisco sources; none of the LI data match the Oaxaca fields.

The 14 Soconusco artifacts (Fig. 1) come from excavations at two Late Postclassic sites dating to after 1350 A.D. (*25*) and include bells, needles, and axe-monies. Copper deposits and metal artifacts are uncommon in this region. The LI ratios plot within Michoacan's Inguarán-Bastán fields (Fig. 5 and Table 4). Nine artifacts—bells, needles, and axe-monies—are copper-tin or copper-arsenic bronze or an alloy of copper-arsenic-tin (Table 4) (*9*) and are west Mexican designs. The LI ratios of two other axe-monies, a miniature T-shaped variety 1.5 cm in length, also match the Michoacan field. Numerous examples of this T-shaped axe-money type appear in Oaxaca (*1, 4, 23*). They occasionally are reported from Guerrero and the State of Mexico. The probability is low that these items were made from Michoacan metal. A copper deposit with an Inguarán-Bastán–like signature may exist near Oaxaca. None of the Soconusco LI ratios plot within the Oaxaca ore fields (Fig. 2) (*9*).

Approximately 120 copper, copper-tin bronze, and copper-arsenic bronze artifacts have been recovered at Platanito and Vista Hermosa, two Huastec settlements located in Tamaulipas (Fig. 1) dating to after 1420 A.D. All but a few are bells (*9*), many made from copper-arsenic and copper-tin bronze and copper-arsenic-tin alloys. Hosler and Stresser-Péan (*3*) suggested that these arti-

Table 4. Paredón (P) and Soconusco (S) probable ore source fields by artifact type, number, and composition.

Artifact	Number of artifacts					
	Jalisco		Michoacan		Unknown	
	P	S	P	S	P	S
Bells						
Cu	–	–	–	1	–	–
Cu-As	–	–	–	1	–	–
Cu-Sn	–	–	1	1	–	–
Cu-As-Sn	–	–	–	2	–	–
Tweezers						
Cu-As-Sn	–	–	1	–	–	–
Sheet						
Cu	1	–	1	–	–	–
Cu-As	–	–	3	–	–	–
Needles						
Cu	1	–	3	–	1	–
Cu-As	–	–	2	2	–	–
Cu-Sn	1	–	–	–	–	–
Axe-monies						
Cu	–	–	1	2	–	–
Cu-As	–	–	–	2	–	–
Unidentified						
Cu	–	–	–	–	1	–
Cu-As	–	–	1	–	–	–
Cu-Sn	–	–	–	1	–	–

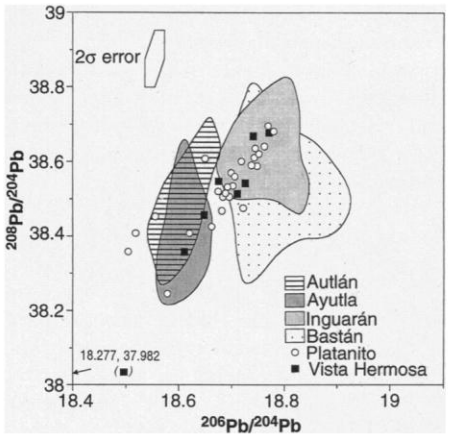

Fig. 6. LI ratios of artifacts from Platanito and Vista Hermosa. Ore fields are as in Fig. 4.

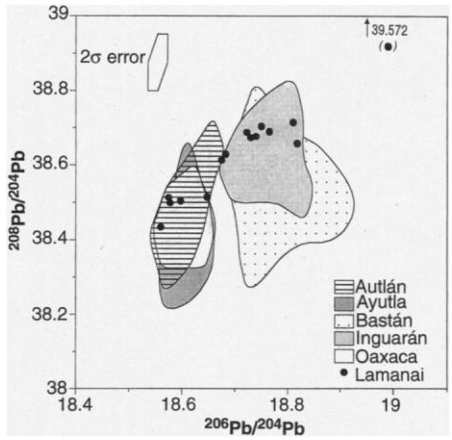

Fig. 7. LI ratios of artifacts from Lamanai. Taviche and Los Ocotes deposits are represented by the "Oaxaca" field; ore fields are as in Fig. 4.

facts might have been cast locally (copper deposits occur in the region, and a copper-arsenic-tin ingot and two pieces of intermediate processing material were excavated from a Vista Hermosa burial) or might have been made in western Mexico, likely Guerrero. These bell types also appear in Michoacan (*26*). LI ratios of 32 artifacts point primarily to Inguarán and Bastán sources (Fig. 6 and Table 5); the signatures of seven of these items match Jalisco deposits, and others come from sources that do not match any of our fields. None matches the Veracruz (Las Minas) or Oaxaca fields.

Lamanai, a large Maya center in Belize, yielded more than 100 metal artifacts, 20 of which we analyzed (*4, 9*). Copper deposits do not exist in the region. Lamanai was occupied continuously from around 200 B.C. through the Spanish invasion. Metal artifacts come from burials, middens, and structures; those we studied date to after 1300 A.D. Nine of the Lamanai artifacts plot within Michoacan source fields (Fig. 7). These include bells, a copper-tin bronze tweezer, sheet metal items, and several lost wax–cast button-like ornaments. These button ornaments do appear in Michoacan but are found in many other Mesoamerican areas as well. Five Lamanai artifacts plot within Jalisco or Oaxaca. Jalisco ores are an unlikely source for at least two of these items, an elaborate filigree ring and a filigree button ornament (Table 6). These particular types rarely, if ever, occur in western Mexico but are reported from Oaxaca and the southeast Maya area. The provenance of the other Lamanai artifacts whose ratios place them within the Jalisco or Oaxaca fields cannot be determined on the basis of design or composition (*9*).

Table 5. Platanito (P) and Vista Hermosa (V) probable ore source fields by artifact type, number, and composition.

Artifact	Number of artifacts					
	Jalisco		Michoacan		Unknown	
	A	V	A	V	A	V
Bells						
Cu	4	2	2	–	1	1
Cu-As	1	–	7	2	–	–
Cu-Sn	–	–	6	–	2	–
Cu-As-Sn	–	–	–	1	–	–
Axes						
Cu-Sn	–	–	–	1	–	1
Unidentified						
Cu-Sn	–	–	1	–	–	–

Copper Sources, Metal Production, and Metals Trade

Our data identify several metal-producing regions in Michoacan and Jalisco. Copper deposits were exploited at Inguarán and

Table 6. Lamanai probable ore source fields by artifact type, number, and composition.

Artifact	Number of artifacts		
	Jalisco/ Oaxaca	Michoacan	Unknown
Bells			
Cu	3	2	1
Tweezers			
Cu-Sn	–	1	–
Rings			
Cu	1	–	–
Ornaments			
Cu	1	2	–
Sheet			
Cu-Sn	–	1	–
Axes			
Cu	–	1	–
Unidentified			
Cu	–	1	–
Cu-As	–	1	–

Bastán, in the Autlán and Ayutla regions, and at other, still unidentified, metalworking zone deposits. Copper and bronze artifacts recovered at Atoyac and Urichu were made from metal smelted from these ores. Objects made from metal smelted from these same west Mexican ores were transported to Aztec and Huastec settlements, to Oaxaca, to the Soconusco, and to Belize. Many artifacts, particularly bells, needles, and tweezers, are made from copper-tin or copper-arsenic bronze.

The production of bronze in two or more regions of the west Mexican metalworking zone indicates that the knowledge required to make these alloys was not restricted to a particular cultural or ethnic group or to a circumscribed geographical area. In ancient West Mexico, bronze objects such as bells, tweezers, and rings were sacred and status items that were worn and used by religious functionaries and leaders. Our data indicate that no single west Mexican political entity managed the production of these bronze status items. Metalworking centers flourished in various areas of this mineral-rich zone, apparently overseen by local ethnic and cultural groups.

Who transported metal objects from these Jalisco and Michoacan production centers to central, northeastern, and southern Mesoamerica? Long-distance commerce in Late Postclassic times was extensive. Merchants operating at the local and regional levels were active in many areas, including Jalisco and Michoacan, as were the *Pochteca*, Aztec merchant guilds. Research on Tarascan and Aztec commerce (*27*) emphasizes that items such as obsidian were exchanged through nonofficial channels (*28*), and this probably was also true of the copper and bronze artifacts we have identified here. Formal trade between Tarascan and Aztec polities is not likely because Aztec and Tarascan peoples were at war along their common border, which ran south from the State of Mexico into Guerrero. West Mexican metal objects excavated at the Aztec towns of Yautepec and Cuexcomate were probably moved to the Tarascan-Aztec border from Michoacan and Jalisco by local merchants through regional marketing systems. Merchants in the multiethnic border communities probably then carried the bells, needles, and tweezers identified here into Aztec trade systems, either through *Pochteca* or regional merchants, and these same networks conveyed the items to Morelos.

The west Mexican artifacts recovered at Paredón and in the Soconusco present a more complex picture. These also may have been transported through Oaxaca to the Soconusco by *Pochteca* or by local or regional merchants. West Mexican artifact types (copper-tin bronze bells) sometimes appear in the valley of Oaxaca, but we have no LI data for them. The dense concentration of metal artifacts at Paredón and its coastal location raise the possibility that the Paredón and Soconusco artifacts were moved south by canoe from west Mexican ports. Such a West Mexico–Oaxaca seagoing trade system has been proposed for textiles, metal objects, and other exotic goods (*29*).

We do not know how artifacts with Michoacan LI signatures made their way to Lamanai. One possibility is to Paredón by canoe, across the isthmus of Tehuantepec, then by canoe around the Yucatan Peninsula. Canoe trade along the east coast of Mesoamerica was reported at the time of the Spanish invasion. This same system may account for other west Mexican goods recovered in the Maya area: Zinapecuaro obsidian has been identified on the island of Cozumel (*30*) dating to the Late Postclassic Period, and copper-tin bronze artifacts of west Mexican design occasionally appear at archaeological sites in the Yucatan and in the Chiapas highlands (*4*). Huastec peoples at Platanito and Vista Hermosa apparently imported many objects from Michoacan and Jalisco, rather than crafting them locally. These items, like those found at Yautepec and Cuexcomate, probably were moved across the Tarascan-Aztec frontier by regional merchants, then into Aztec or other marketing networks.

Thus, copper and bronze artifacts, made from west Mexican ore metal and west Mexican in design, appear at a variety of Mesoamerican settlements. These bells, tweezers, needles, and other items are not local Maya, Huastec, or Aztec copies of west Mexican designs. Copper deposits exist near some of these settlements, but the LI data indicate that metal from the deposits we sampled could not have served as parent material for these artifacts. Because LI signatures should broadly reflect the overall isotopic west-east trend, other deposits in these same regions were unlikely to have provided metal for these artifacts.

West Mexican peoples produced one of Late Postclassic Mesoamerica's premier exotic goods: artifacts made from copper and bronze alloys. They also were involved in the distribution of these items. One way in which Mesoamerican polities interacted during this time was through exchange in exotic and luxury objects (*31*). For Mesoamerican peoples, any metal object probably took on the character of a luxury item. Metal was relatively new in Mesoamerican history, introduced after the Classic Period civilizations (Maya, Teotihuacan) had been flourishing for hundreds of years. Metal objects were uncommon except in the metalworking zone. Some items (such as needles) may have been particularly appreciated for their superior mechanical characteristics, others (such as axe-monies) because they served as a form of wealth. Those metal objects thought to embody sacred power, especially copper-tin bronze bells with a high tin content, carried the greatest symbolic weight. For west Mexican peoples, metallic bell sounds, used in ritual, reproduced the sounds of rain and thunder and promoted human and agricultural fertility; the golden and silvery colors of these bells, and of sheet metal objects such as tweezers, represented solar and lunar deities (*32*). These artifacts, through their sounds and their colors, affirmed the political power and supernatural affiliations of the individuals who used them. These and other metal objects may have conferred the same sacred power on people who acquired them in other Mesoamerican regions. Late Postclassic Period west Mexican polities became major participants in broader Mesoamerican interaction networks by producing and exporting artifacts made from an exotic and symbolically powerful material.

REFERENCES AND NOTES

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6. Most ore analyses were of mixed-ore minerals from strongly mineralized hand samples, to ensure that they were representative of materials that may have been smelted. Some ore samples were separated fractions of pyrite, chalcopyrite, cuprite, goethite, or bornite. Analyses of separate minerals did not differ systematically from those of bulk samples within error. Artifacts were analyzed by nitric acid dissolution of cleaned metal slivers. Samples were washed in dilute nitric acid before dissolution, then diluted so that 1 μg of Pb was purified using standard HBr chemistry; samples of 200 to 500 ng were analyzed by the phosphoric acid–silica gel emitter technique on rhenium filaments. Data were collected on MAT 262 multicollector mass spectrometers at the U.S. Geological Survey (Menlo Park, CA), on a Micromass MM3O at Geospec Consultants Ltd. (Edmonton, Alberta, Canada), on a VG single-collector instrument at Chempet Research Corporation (Moorepark, CA), and on a VG Sector 54 multicollector at Geochron (Cambridge, MA). Each measurement comprised 40 to 80 sets of multicollector ratios or 100 to 200 single-collector scans. External 2σ errors were better than 0.05% per amu (0.1% on the $^{206}Pb/^{204}Pb$ ratio and 0.2% on the $^{208}Pb/^{204}Pb$ ratio). In-run precisions were nearly always better than 0.01% per amu. Measurements were normalized to the National Bureau of Standards SRM 981 and 982 LI standards; replicate analyses of the same samples (and of different samples from the same deposits) made in different laboratories were consistent within the stated errors. Ore fields enclose the 2σ envelopes

of all analyses. Chemical compositions of artifacts were determined by inductively coupled plasma mass spectrometry and neutron activation analyses.
7. The geographical distribution of copper and copper alloy artifact designs and compositional types is well established (*1–4*).
8. We also analyzed 15 samples from a lead-zinc-silver deposit in the State of Mexico and rock samples from Puebla to establish overall trends (A. Macfarlane and D. Hosler, in preparation).
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34. Ore sampling was carried out by D.H. with the assistance of Mexico's Consejo de Recursos Minerales. Archaeological sampling was done under permits granted by Mexico's Instituto Nacional de Antropología e Historia to D.H. Funding was provided by Grupo México (Industrial Minera México), American Smelting and Refining Company, and Southern Peru Copper, in a grant to D.H. The National Geographic Society funded chemical analyses of Urichu artifacts in a grant to H. Pollard with a subcontract to D.H. We thank these institutions for their support. We thank T. Tartaron, J. Pinson, and G. Roulette for assistance with data processing. W. Powell rendered the map.

RESEARCH ARTICLE

Highly Diverged U4 and U6 Small Nuclear RNAs Required for Splicing Rare AT-AC Introns

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Removal of a rare class of metazoan precursor messenger RNA introns with AU-AC at their termini is catalyzed by a spliceosome that contains U11, U12, and U5 small nuclear ribonucleoproteins. Two previously unidentified, low-abundance human small nuclear RNAs (snRNAs), U4atac and U6atac, were characterized as associated with the AT-AC spliceosome and necessary for AT-AC intron splicing. The excision of AT-AC introns therefore requires four snRNAs not found in the major spliceosome. With the use of psoralen crosslinking, a U6atac interaction with U12 was identified that is similar to a U6-U2 helix believed to contribute to the spliceosomal active center. The conservation of only limited U6atac sequences in the neighborhood of this interaction and the potential of U6atac to base pair with the 5′ splice site consensus for AT-AC introns provide support for current models of the core of the spliceosome.

The majority of eukaryotic precursor messenger RNA (pre-mRNA) introns contain sequences at their 5′ and 3′ splice sites that conform to the GU-AG consensus. Excision of these introns occurs in a large and dynamic complex, the spliceosome, which is composed of U1, U2, U4-U6, and U5 small nuclear ribonucleoproteins (snRNPs) and a number of non-snRNP protein factors. In vitro spliceosome assembly involves sequential binding of these trans-acting factors to the pre-mRNA (*1*). Initially, U1 and U2 snRNPs bind the 5′ splice site and the branch site, respectively, through base-pairing interactions. The preformed U4-U6·U5 tri-snRNP subsequently joins the presplicing complex and establishes multiple snRNP-snRNP as well as pre-mRNA–snRNP interactions. U6 is a highly conserved snRNA that base pairs extensively with U4. Displacement of U1 and U4 snRNPs during spliceosome assembly allows U6 to base pair with the 5′ splice site and with U2 snRNA, juxtaposing the 5′ splice site and the branch nucleotide, whose 2′ hydroxyl group serves as the nucleophile for the first step of splicing. The reaction intermediates are the excised 5′ exon and the lariat intron–3′ exon. The second transesterification reaction involves nucleophilic attack at the 3′ splice junction by the 3′-hydroxyl of the liberated 5′ exon, yielding the ligated exons and the lariat intron.

A minor class of pre-mRNA introns (AT-AC introns) has been found in metazoan genes (*2, 3*) including the gene *P120*, which codes for a proliferation-associated nucleolar protein in several mammals. Their 5′ splice site and branch site consensus sequences are ATATCCTT and TC-

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