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Research Article

West Mexican Copper Metallurgy: A Case Study from Teuchitlán, Jalisco

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Abstract

Metallurgy and metalworking in the form of sumptuary objects, represented one of the most characteristic socio-technological developments in Pre-Columbian Western Mexico. Such precious goods were used as symbols of social and political elite status, as well as in religious ceremonies and other rituals, though some utilitarian implements were also crafted. Based primarily on copper and its alloys, this technology represents a valuable reference for understanding the cultural context in which it developed. The present paper discusses research pertaining to the West Mexican site of Teuchitlán, Jalisco, framed in the general context of mining and metallurgy in the region. This work represents a systematic attempt to characterize the metallurgy associated with the Teuchitlán Tradition, a pre-Hispanic complex society whose rise and development have been generally dated from the end of the Formative period (200 CE) to the end of the Classic era in Mesoamerica (ca. 900 CE). Twenty-nine metal samples, including adornments such as lost–wax-cast bells and cold-worked rings, as well as implements, including needles and awls, have been analised by wavelength-dispersive electron probe microanalysis (WDS-EPMA) and micro-X-ray fluorescence (μ-XRF). Preliminary results using the electron microprobe based on wavelength-disperse scans and subsequent quantitative analysis of Cu and Ag indicate that most of the samples are almost pure copper with trace amounts of silver. Preliminary analysis using μ-XRF indicated that small amounts of additional elements such as Fe, Zn, Mo, Sb and Sn also occur.

Keywords: Archaeometallurgy; Ancient copper; Western Mexico

Introduction

New World metallurgy first emerged in the Andean region of South America between the Initial Period (1800 to 900 B.C.) and the Early Horizon (900 to 200 CE) [1]. In Mesoamerica, metallurgy and metalworking developed much later, with the earliest estimates at ca. 800 CE [2,3]. This late date of the appearance of metals and the similarity of the techniques employed by the native metalsmiths to those developed in South America has led many scholars to suggest that metal objects and metallurgical techniques were introduced into West Mexico from Peru and Ecuador, by traders using watercraft capable of long-distance voyages along the Pacific coast of South and Central America [2,4,5,6]. Whether this is an accurate assumption, nevertheless, still a matter of debate.

The Mexican territory is an area where copper and other metallic minerals are present in relative abundance. A distinctive metallurgical tradition flourished in this region for nearly a millennium before the Spanish Contact [2, 209]. Throughout Mesoamerica a wide range of metal artefacts were fashioned from the Late Classic through the Late Post-Classic. During this period of time, metallurgy became part of the social fabric of ancient Mesoamerican life [2,7]. Copper and copper-based artefacts (mainly those made of copper alloyed with tin, arsenic, or lead) are found throughout much of Mesoamerica by Early Post-Classic times, having been distributed via a well-developed trade and tribute networks.

The earliest metal artefacts produced in Mesoamerica come from sites along the coast of western Mexico, including Tomatlán, Jalisco and Amapa, Nayarit, as well as settlements in the Lower Rio Balsas, between Michoacán and Guerrero, in the Infiernillo region (Map 1). These sites date from ca. 800 CE [2,3]. All objects associated within these contexts are made of copper and represent two traditions of production: some were lost-wax cast (bells and small ornaments), others cold-worked from an initial cast blank, and included ornaments and tools [2]. This technology based on copper and/or its practitioners, moved inland toward the basins of Jalisco and Michoacán, where copper objects have been recovered in places like Cojumatlán, Michoacán and Tizapán, Jalisco, both located in the Lake Chapala basin [2,8].

Map 1: West Mexico in the context of Mesoamerica.

Early copper artefacts, both from coastal and inland sites, fall within a range of dates from 800 to 1100/1200 CE [2,3]. In La Peña [9,10], a recently excavated site located in the Sayula Basin, adjacent to Lake Chapala, copper objects dating from between 800 and 1100 CE. have been recovered [9]. La Peña artefacts consist of small cast copper bells and cold worked objects: open rings, needles and tweezers. In fact, all analysed artefacts that belong to this period, except for a statue of copper and arsenic excavated in the Atetelco complex in Teotihuacan, in 1998 [11], are made of copper. Unfortunately, thus far, no systematic research of mining sites and production workshops, have been conducted in western Mexico.

The present work is part of a long-term and still on-going project, which investigates social complexity and regional development in the Teuchitlán Valley, in Central Jalisco, Mexico. Guachimontones is the largest archaeological site of the Teuchitlán tradition, located on the outskirts of the town of Teuchitlán. The centre of the ancient settlement contained three circular plazas, each with a circular multi-level pyramid on top. A total of 10 "circles", four rectangular plazas and two ballgame courts and other smaller structures have been identified within the site. Although evidence of Teuchitlán tradition architecture appears as early as 300 BCE, its rise is generally dated to the end of the Late Preclassic Period, around 200 CE. The tradition seems to end rather abruptly at the end of the Classic Period, ca. 900 CE [12,13].

The Archaeological Research Project "Los Guachimontones" directed by the late Prof. Phil C. Weigand, involved several fieldwork seasons. The excavation of several household units in sectors, labelled Talleres 1 and 2 in 2001-2002, provided evidence of the presence of metalwork in the area [14]. Later in 2008-2010, some more artefacts were recovered, which had apparently been deposited as offerings at a ballgame court [15]. The project's artefact collection currently includes various categories of metal artefacts, as shown in (Table 1) (Figure 1).

Table 1: Metal artefacts from excavated contexts at Teuchitlán.

Object	Type	Technique	Sector	Number
Bells	1a, 2a [2, 55]	Lost-wax cast	Ballgame court	9
Rings	Simple, composed	Cold-worked an/or heat annealed	Talleres 2	9
Pendants	Plate	Cold-worked	Talleres 3	1
Needles	Loop-eye	Cold-worked and/or heat annealed	Talleres 1	2
Awls	Curved double point	Cold-worked and/or heat annealed	Talleres 1	3
Perforators	Miscellaneous	Cold-worked and/or heat annealed	Talleres 2/3	5
			Total	29 Artefacts

Figure 1: Metal artefacts from excavated contexts at Teuchitlán: a) three copper bells, from Ballgame court; b) copper ring with green stone bead, from Talleres 2; c) copper loop eye needle, from Talleres 2; d) metal plate with upper perforation, from Talleres 3.

The techniques used in the fashioning of the metal objects found in Teuchitlán involve two basic methods: metal casting, and cold work. Specifically, bells were produced by the technique known as 'lost wax' casting. The making of other metal objects, including needles, tweezers, awls, and axes, was the result of a number of hammering and annealing sequences, and involved the use of native copper from an original cast blank. The operational chain of metal-object production is still unknown, as no direct or indirect evidence of metallurgical production has yet been found in the region. It is also likely that the recovered objects were produced in other regions and eventually introduced by exchange.

Materials and Methods

a. EPMA-WDS (wavelength-dispersive electron probe microanalysis, only analysis of Cu and Ag)

b. EPMA-EDS (energy-dispersive electron probe microanalysis)

c. EDS μ -XRF vacuum (micro-XRF analysis in vacuum, measured 2019)

d. EDS μ -XRF air (micro-XRF analysis in air, measured 2015, 2016)

This research involves documentation and sampling of already-excavated artefacts from the collection of the Archaeological Research Project "Los Guachimontones". Saw-cut samples were obtained from 24 of these objects, and analysed by electron microprobe (Table 2) and micro-XRF (energy-dispersive X-ray fluorescence) for major and some minor (trace) elements (Table 3). The samples have been examined by wavelength-dispersive electron microprobe analyses (EMP), examining ca. 3-5 points per sample to get some statistics (Table 2). The diameter of the analysis spot is ca. 3 microns in EMP analysis and ca. 25 microns in (polycapillary lens-focussed) micro-XRF analysis, and the analyses are in element wt.%. Note that micro-XRF analyses are normalized to 100 wt.%.

Table 2: Electron probe microanalyses EPMA-WDS of Cu-metals.

Sample Nr.	Cu	Ag	Total	Comment	Sample Nr.	Cu	Ag	Total	Comment
68CA1_01	100.39	0.10	100.49	Cu-Metal	103_1	85.85	0.09	85.95	Cu-Sn Metal
68CA1_2	99.03	0.09	99.12	Cu-Metal	103_2	84.58	0.12	84.70	Cu-Sn Metal
213-A2_1	99.64	0.08	99.72	Cu-Metal	103_3	89.84	0.09	89.93	Cu-Sn Metal
213-A2_2	99.86	0.08	99.94	Cu-Metal	103_4	73.90	0.24	74.14	Cu-Sn Metal
213-A2_3	99.28	0.07	99.35	Cu-Metal	104_1	98.61	0.08	98.69	Cu-Metal
761_1	99.60	0.05	99.65	Cu-Metal	104_2	98.63	0.10	98.73	Cu-Metal
761_2	99.68	0.05	99.73	Cu-Metal	104_3	98.10	0.11	98.21	Cu-Metal
761_3	98.43	0.05	98.48	Cu-Metal	68A-A1_1	99.23	0.09	99.32	Cu-Metal
68CA3_1	100.29	0.07	100.36	Cu-Metal	68A-A1_2	99.09	0.09	99.18	Cu-Metal
68CA3_2	98.96	0.10	99.06	Cu-Metal	68A-A1_3	99.50	0.05	99.55	Cu-Metal
68CA3_3	99.62	0.09	99.71	Cu-Metal	105_1	100.00	0.15	100.15	Cu-Metal
160_1	100.26	0.37	100.63	Cu-Metal	105_2	100.44	0.08	100.52	Cu-Metal
160_2	100.29	0.30	100.59	Cu-Metal	105_3	99.81	0.10	99.91	Cu-Metal
160_3	99.99	0.28	100.27	Cu-Metal	107_1	98.78	0.08	98.86	Cu-Metal
68BA1_1	97.87	0.12	97.99	Cu-Metal	107_2	99.50	0.09	99.59	Cu-Metal
68BA1_2	97.09	0.14	97.23	Cu-Metal	107_3	98.41	0.06	98.47	Cu-Metal
68BA1_3	97.87	0.09	97.96	Cu-Metal	213 A1_1	99.57	0.18	99.75	Cu-Metal
68BA1_5	97.95	0.12	98.07	Cu-Metal	213 A1_2	99.54	0.18	99.72	Cu-Metal
214_1	98.82	0.05	98.87	Cu-Metal	213 A1_3	99.98	0.20	100.18	Cu-Metal
214_2	98.93	0.08	99.01	Cu-Metal	68CA2_1	86.91	0.41	87.32	Cu-Sn Metal
214_3	99.11	0.06	99.17	Cu-Metal	68CA2_2	96.24	0.11	96.35	Cu-Sn Metal
215-1_1	99.86	0.14	100.00	Cu-Metal	68CA2_3	94.23	0.16	94.39	Cu-Sn Metal
215-1_2	100.17	0.13	100.30	Cu-Metal	68CA2_4	86.90	0.42	87.32	Cu-Sn Metal
215-1_3	99.75	0.13	99.88	Cu-Metal	68CA2_5	90.22	0.29	90.51	Cu-Sn Metal
215-5_1	100.64	0.17	100.81	Cu-Metal					
215-5_2	99.50	0.17	99.67	Cu-Metal					
215-5_3	98.84	0.13	98.97	Cu-Metal					

The analyses are given in element wt %.

Table 3: EDS m-XRF analyses of Cu-metals in vacuum.

Sample Nr.	Cr	Fe	Co	Cu	Zn	As	Mo	Ag	Cd	Sn	Sb	Te	Hg	Pb	Total	Comment
107	0.06	0.1	0.01	99.15	0.27	n.d.	0.16	0.06	0.02	n.d.	0.02	0.11	0.01	0.03	100	Cu-Metal
107	0.07	0.12	0.01	99.06	0.25	n.d.	0.19	0.06	0.05	n.d.	0.02	0.11	0.04	0.02	100	Cu-Metal
105	0.04	0.1	0.01	99.14	0.2	0.01	0.2	0.09	n.d.	n.d.	0.05	0.12	0.04	0.01	100	Cu-Metal
105	0.09	0.13	n.d.	99.08	0.24	n.d.	0.18	0.09	0.05	n.d.	n.d.	0.09	0.03	0.03	100	Cu-Metal
68A-A1	0.02	0.06	0.01	99.26	0.23	n.d.	0.16	0.06	0.01	n.d.	0.02	0.12	0.03	n.d.	100	Cu-Metal
68A-A1	0.01	0.02	n.d.	99.3	0.24	n.d.	0.2	0.08	0.01	n.d.	n.d.	0.13	n.d.	0.01	100	Cu-Metal
68A-A1	0.01	0.11	n.d.	99.08	0.3	n.d.	0.19	0.06	0.02	n.d.	0.02	0.11	0.07	0.03	100	Cu-Metal
213 A1	0.03	0.11	n.d.	99.11	0.24	n.d.	0.19	0.09	0.05	n.d.	0.06	0.08	n.d.	0.04	100	Cu-Metal
213 A1	0.17	0.14	0.01	98.95	0.23	n.d.	0.17	0.17	0.01	n.d.	0.01	0.07	0.04	0.01	100	Cu-Metal
213 A1	0.03	0.09	n.d.	99.14	0.25	n.d.	0.16	0.14	0.02	n.d.	0.06	0.09	0.03	n.d.	100	Cu-Metal
104	0.13	0.02	0.01	98.79	0.35	n.d.	0.18	0.09	n.d.	n.d.	0.02	0.13	n.d.	0.28	100	Cu-Metal
104	n.d.	0.01	0.01	99.6	0.03	n.d.	0.18	0.07	n.d.	n.d.	0.03	0.06	n.d.	n.d.	100	Cu-Metal
104	0.33	0.03	0.01	99	0.19	n.d.	0.16	0.13	n.d.	n.d.	n.d.	0.09	0.03	0.02	100	Cu-Metal
103	0.08	0.08	n.d.	90.4	0.19	0.01	0.14	0.05	0.07	8.45	0.3	0.2	0.01	0.02	100	Cu-Sn Metal
103	0.09	0.07	n.d.	90.35	0.17	0.01	0.1	0.07	0.08	8.53	0.21	0.3	n.d.	0.02	100	Cu-Sn Metal

68CA-2	0.03	0.17	n.d.	94.19	0.28	n.d.	0.13	0.12	0.07	4.66	0.14	0.13	0.06	0.02	100	Cu-Sn Metal
68CA-2	0.03	0.24	n.d.	94.03	0.23	n.d.	0.14	0.15	0.03	4.7	0.19	0.12	0.11	0.02	100	Cu-Sn Metal
68CA-2	0.02	0.15	n.d.	95.2	0.2	n.d.	0.12	0.1	0.05	3.83	0.08	0.17	0.01	0.07	100	Cu-Sn Metal
215-5	0.03	0.15	n.d.	98.77	0.11	0.02	0.21	0.09	0.28	n.d.	0.23	0.1	0.01	n.d.	100	Cu-Metal
215-5	n.d.	0.31	n.d.	98.36	0.17	0.02	0.16	0.04	0.2	0.14	0.26	0.27	0.06	0.01	100	Cu-Metal
215-5	0.01	0.12	n.d.	98.91	0.15	0.01	0.18	0.09	0.14	0.02	0.1	0.24	n.d.	0.01	100	Cu-Metal
215-1	0.01	0.15	n.d.	98.74	0.21	0.04	0.14	n.d.	0.21	0.14	0.24	0.1	n.d.	0.01	100	Cu-Metal
215-1	n.d.	0.14	n.d.	99.01	0.14	0.02	0.15	n.d.	0.06	0.3	0.12	n.d.	n.d.	0.05	100	Cu-Metal
215-1	n.d.	0.14	n.d.	98.75	0.28	0.01	0.16	0.06	0.23	0.02	0.22	0.04	n.d.	0.07	100	Cu-Metal
68BA1	0.01	0.08	0.01	99.28	0.17	n.d.	0.17	0.08	0.03	n.d.	0.04	0.13	n.d.	n.d.	100	Cu-Metal
68BA1	0.02	0.06	0.01	99.17	0.2	n.d.	0.18	0.05	0.06	n.d.	n.d.	0.14	0.08	0.02	100	Cu-Metal
68BA1	n.d.	0.12	n.d.	99.02	0.26	n.d.	0.18	0.08	0.01	n.d.	0.06	0.17	0.01	0.1	100	Cu-Metal
761	0.02	0.19	0.02	98.99	0.25	n.d.	0.2	0.06	0.04	n.d.	0.02	0.08	0.1	0.03	100	Cu-Metal
761	0.07	0.11	n.d.	99.19	0.18	n.d.	0.16	0.04	0.02	n.d.	0.02	0.17	0.02	0.01	100	Cu-Metal
761	0.11	0.11	0.01	99.09	0.27	n.d.	0.17	n.d.	0.03	n.d.	n.d.	0.14	0.07	0.02	100	Cu-Metal
68CA1	0.01	0.46	n.d.	98.53	0.24	n.d.	0.19	0.12	0.04	n.d.	0.04	0.16	0.09	0.1	100	Cu-Metal
68CA1	0.01	0.07	n.d.	99.46	0.11	n.d.	0.18	0.11	0.03	n.d.	n.d.	0.03	n.d.	n.d.	100	Cu-Metal
68CA1	n.d.	0.02	0.01	99.17	0.22	n.d.	0.2	0.1	0.08	n.d.	0.05	0.06	0.07	0.01	100	Cu-Metal
213-A2	0.09	0.09	n.d.	99.28	0.13	n.d.	0.16	0.07	n.d.	n.d.	0.06	0.1	0.01	0.01	100	Cu-Metal
213-A2	0.08	0.08	0.01	99.2	0.24	n.d.	0.17	0.06	0.01	n.d.	0.02	0.09	0.03	0.02	100	Cu-Metal
213-A2	0.05	0.11	n.d.	99.23	0.21	n.d.	0.18	0.05	0.03	n.d.	0.02	0.1	0.02	0.01	100	Cu-Metal
160	0.04	0.11	0.02	98.98	0.25	n.d.	0.18	0.22	n.d.	n.d.	0.06	0.08	0.03	0.02	100	Cu-Metal
160	0.04	0.09	0.01	99	0.26	n.d.	0.17	0.22	0.03	n.d.	0.01	0.15	0.01	0.02	100	Cu-Metal
68CA3	0.04	0.05	0.01	99.25	0.25	n.d.	0.17	0.07	n.d.	n.d.	0.05	0.05	0.05	0.02	100	Cu-Metal
68CA3	0.09	0.05	0.01	99.23	0.24	n.d.	0.16	0.05	0.01	n.d.	0.01	0.11	0.03	n.d.	100	Cu-Metal
68CA3	0.16	0.15	0.02	98.89	0.2	n.d.	0.19	0.04	n.d.	n.d.	0.04	0.18	0.12	n.d.	100	Cu-Metal
214	0.05	0.09	0.01	98.9	0.26	n.d.	0.16	0.02	0.15	0.02	0.18	0.11	0.03	0.02	100	Cu-Metal
214	0.08	0.09	n.d.	98.95	0.28	n.d.	0.17	0.05	0.12	n.d.	0.15	0.1	n.d.	n.d.	100	Cu-Metal
214	0.06	0.1	0.01	99.07	0.21	n.d.	0.13	n.d.	0.08	n.d.	0.03	0.25	0.05	0.02	100	Cu-Metal

μ -XRF:

Metals were analysed for minor element chemistry with the Bruker M4 Tornado μ -XRF instrument at the Institute of Mineralogy and Petrography, Innsbruck University. One set of measurements (2019) was done at 20mbar vacuum using a 50kV / 600μA powered rhodium X-ray tube with Be window and a polycapillary optics-focused beam with ~25μm spot size. Two series of measurements (2015, 2016) were done in air. Emitted x-ray energies were analysed with an energy dispersive silicon drift detector (Bruker SDD 530, resolution ≤145eV for Mn-Ka). Dwell times of 60 sec were used for point analyses. Manual spectra quantification was standardless, based on fundamental parameters, and concentrations down to ~0.001% are resolved. All element concentrations are normalized to 100wt%.

EPMA-WDS:

Electron probe microanalysis was performed on a JEOL JXA 8100 SUPERPROBE using the wavelength dispersive mode (WDS) at 15 kV and 10 nA. The counting times were 20 sec on the peak and 10 sec. on the background. Pure Cu and Ag metal was used as standards. Preliminary EPMA-EDS analyses were done using a Thermo-Noran EDS system.

Results and Discussion

Most of the analysed samples are nearly pure copper, with minor amounts of silver (<0.5 wt.%). We run some preliminary energy-dispersive (EDS) elemental scans on several samples on the electron microprobe and found only these two elements; therefore, we quantitatively analysed the samples only for Cu and Ag. Due to the occurrence of significant Sn contents in one sample (103), the analytical EMP totals of this sample are very low, ranging from 74 to 90 wt.%. These Sn concentrations were subsequently verified using micro-XRF (Table 3). Most samples contain small droplets of Cu_2O; two samples contain larger amounts of Sn and two samples contain some Cu-Sb-Bi droplets. On the other hand, micro-XRF analysis showed that additional elements such as Fe, Zn, Mo, Sb and

Sn occur (Table 3). Although more detailed wavelength-dispersive chemical information is required to conclusively determine if, and how metal production was taking place locally in the Teuchitlán Valley, the results obtained so far have been extremely valuable. The results above have enabled us to characterize the different elements present in the metal objects. These results might provide information on the nature of the raw materials used.

The EPMA-WDS results indicate that most of the samples are almost pure copper (98-100 wt.%) with trace amounts of silver (<0.3 wt.%). Two samples (103 and 68CA2) turned out to be bronzes (3.8 - 4.7 and 8.5 wt.% Sn). Trace element analyses by micro-XRF show the additional elements Fe (<0.5 wt.%), Zn (<0.4 wt.%), Cr, Ag, Cd, Sb, Te, Pb (<0.3 wt.%), Mo (<0.2 wt.%). Two bronze samples show highest Sb and Te. In order to obtain refined analyses with new analytical procedures, sixteen samples have been re-analysed using different analytical methods, which will allow comparison with our previous results.

The following figures illustrate the comparisons and differences between the different methods applied to the metal samples.

Figures I) to V) illustrate the variation between the different analytical procedures. The comparison in Figure I) shows that the EPMA data present a marginally bigger scatter than the micro-XRF (vacuum) data. Otherwise, the data are in very good agreement. When comparing μ -XRF-data obtained in air vs. EPMA-WDS data (Figure 2) the μ -XRF data show a shift to higher values, and the agreement is not as good as in (Figure 1) above.

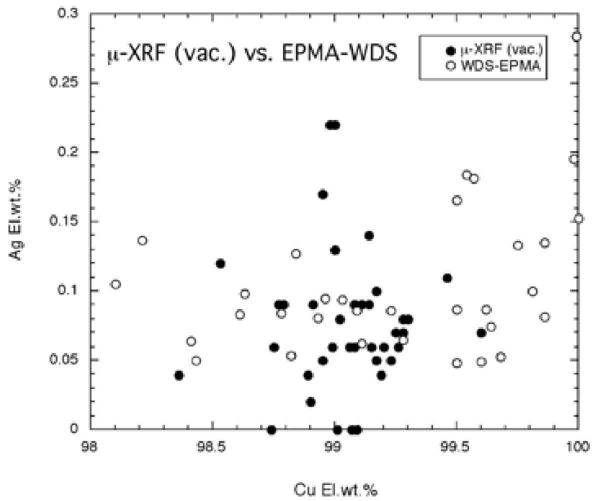

Figure 2: Comparison between Ag vs. Cu measured with μ -XRF and EPMA-WDS. Comparison μ -XRF (vacuum) vs. EPMA-WDS of almost pure copper.

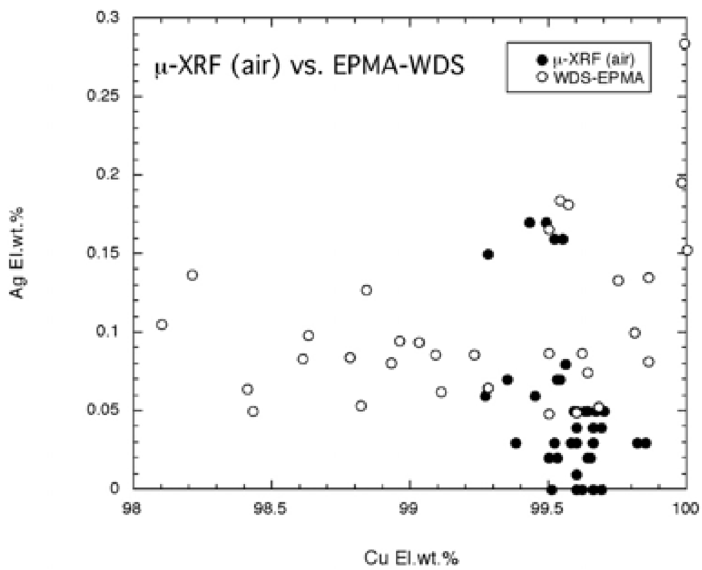

Figure 3: Comparison between Ag vs. Cu measured with μ -XRF (air) and WDS EPMA. Comparison μ -XRF (air) vs. EPMA-WDS of almost pure copper.

(Figure 3) shows the comparison between the μ-XRF (vacuum) and EMPA-EDS analysis in the 100-90 % Cu region. The comparison above 90 wt.% is good but the region below 90 wt.% Cu (bronze) lacks μ-XRF (vacuum) data. EDS analysis also reveals a slight corrosion of the Cu samples since EPMA-EDS data demonstrate that even almost pure copper samples show some measured O concentrations, indicating various degrees of oxidation and the formation of a thin layer of Cu-oxides on the surface (Figure 4). Finally, the comparison between the two μ-XRF analysis procedures is shown in (Figure 5). These figures present the comparison between the vacuum and non-vacuum measurements using the μ-XRF. These figures clearly show that the measurements in vacuum yielded slightly lower Cu contents due to the slightly higher contents of other elements (e.g. Zn, Mo) measured in vacuum. Overall, when it comes to judging μ-XRF measurements there is a significant difference between the results in air and vacuum. Therefore, the XRF analysis should be done in vacuum to prevent interactions between X-rays and air molecules to obtain reliable results (Figure 6).

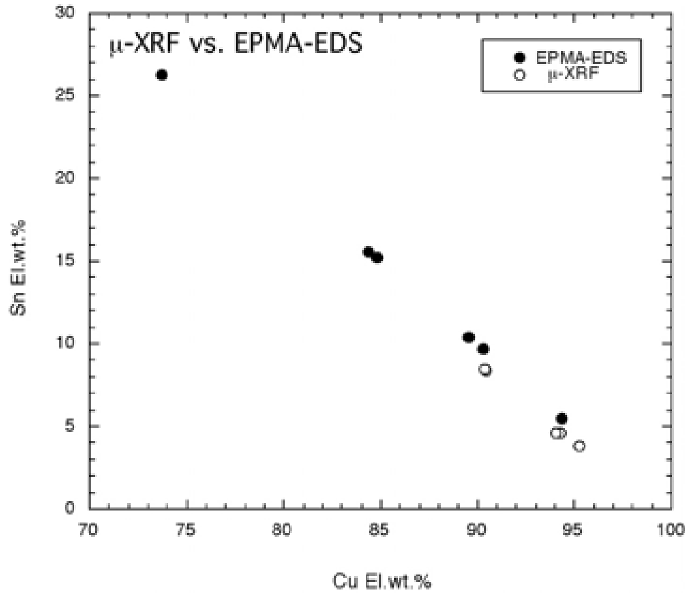

Figure 4: Comparison between Cu vs. Sn in the bronze samples (high Cu region) using the μ-XRF (vacuum) and EMPA-EDS analysis.
Comparison μ-XRF (vacuum) vs. EPMA-EDS of bronze analyses.

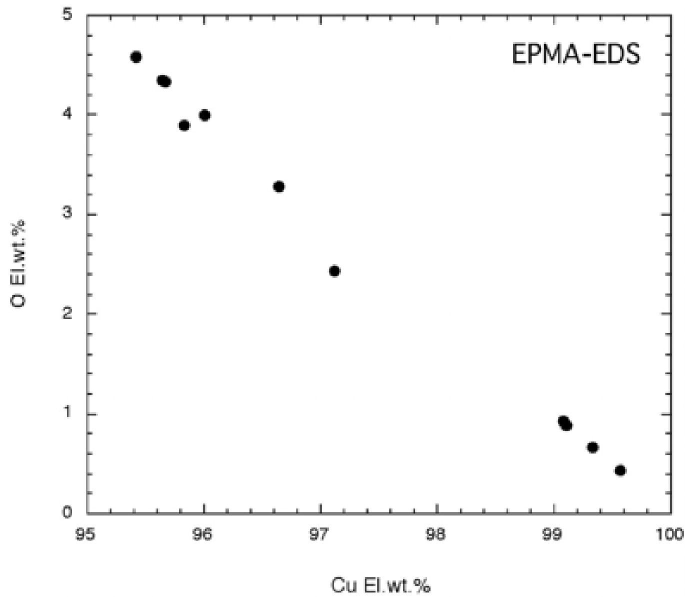

Figure 5: EPMA-EDS data showing Cu vs. O.
EPMA-EDS of high Cu copper.

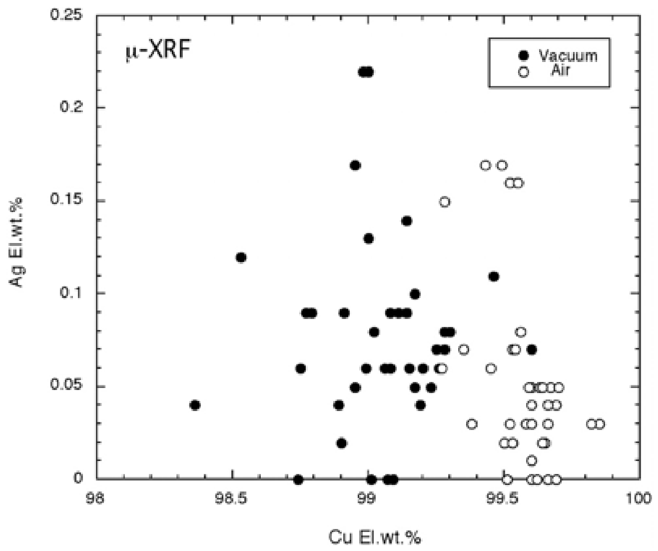

Figure 6: μ -XRF (vacuum) vs. μ -XRF (air) data showing Cu vs. Ag. Comparison μ -XRF (vacuum) vs. μ -XRF (air) of almost pure copper.

Conclusion

a) WDS-EPMA values are the most reliable but should be extended to the other elements (e.g., Sn etc.) besides Cu and Ag similar to the μ -XRF analyses.

b) EDS analysis is only of semi-quantitative nature since it is not a standardized analysis but a fundamental-parameter calibration and thus always normalized to 100 wt.%.

c) In order to assess the degree of corrosion on the pure metal samples oxygen should be analyzed with EPMA-WDS to show if there is surface alteration, as indicated by EPMA-EDS analysis (Figure 7).

d) μ -XRF analysis (even if it is only a fundamental-parameter calibration) should definitely be done in vacuum. Measurements in air tend to shift the concentrations of various elements relative to Cu. These data also agree very well with the EPMA-WDS data.

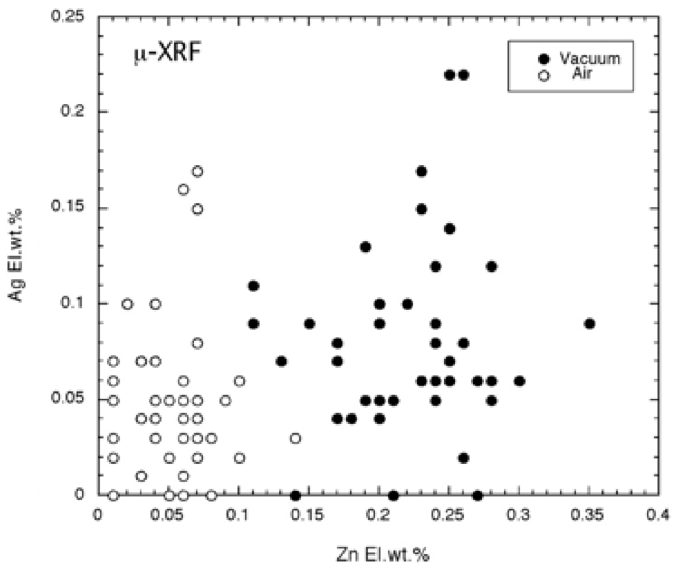

Figure 7: μ -XRF (vacuum) vs. μ -XRF (air) data showing Zn vs. Ag.

Our future research plans include the investigation of the contexts of metal production in the area. The recovery and characterization of production-related materials such as slags and other metallurgical by-products will enable us to reconstruct the technological processes involved in the extraction of the metal from the ore. Geochemical analysis will allow us to explore the all-important relationship between various local ore sources and archaeological slags and furnace sites, and between the copper produced at the identified sites and the metal artefacts from the Teuchitlán region (Figure 8). Once the primary production forms and contexts have been established, efforts will be made to trace any changes in the technology or choice of raw materials. Our aim is to further investigate the origins and development of metallurgy in Western Mexico and Mesoamerica in general.

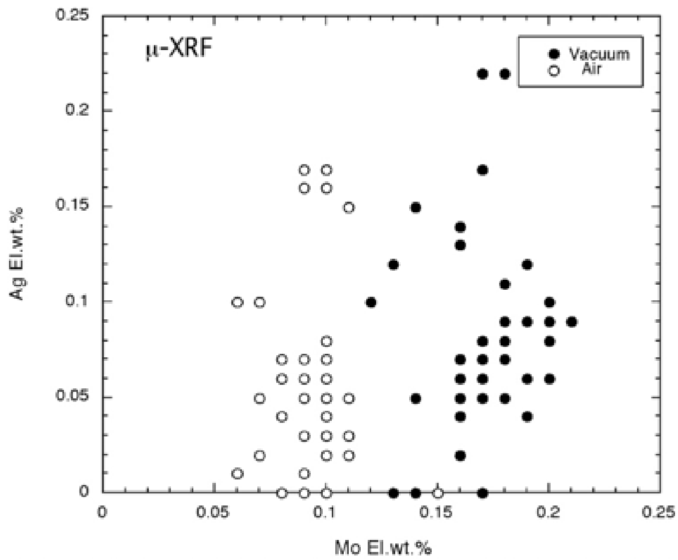

Figure 8: µ -XRF (vacuum) vs. µ -XRF (air) data showing Mo vs. Ag.

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Conflict of Interest

The authors of this paper certify that they have No affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript.

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