NEW DATA ON SCALE PRODUCTION OF COPPER IN THE CULTURE OF THE EL ARGAR. THE DUMPING GROUND FOR PEÑALOSA (BAÑOS DE LA ENCINA, JAÉN)


Abstract

This paper deals with the latest data obtained after the find of a dump containing archaeometallurgical remains, located at the exterior of Peñalosa site. Its study and documentation is to provide important information about a very topical issue on Archaeometallurgy of the southern Iberian Peninsula during the Bronze Age: the scale of production. To this end there have been performed numerous analyses of slags and fragments of vessels used in the reduction of copper ores and melting metal. Technological data obtained along with the quantification of archaeometallurgical material from the whole Penalosa site allow us to conclude the importance of the scale of production of copper in the area, with a major focus on Sierra Morena.

Key words: Upper Guadalquivir, Copper Metallurgy, Metallurgical dump, Argar Culture, Bronze Age.

Resumen

En este trabajo se presentan los últimos datos obtenidos de un hallazgo arqueológico de gran importancia: un vertedero arqueometalúrgico situado al exterior del poblado de Peñalosa. Su estudio y documentación viene a aportar una importante información sobre un tema muy de actualidad en la arqueometalurgia del sur de la Península Ibérica durante la Edad del Bronce: la escala de producción. Para ello se han realizado numerosos análisis de las escorias y los restos de las vasijas utilizadas en la reducción de minerales de cobre y la fundición del metal. Los datos tecnológicos junto con la cuantificación del material arqueometalúrgico localizado en Peñalosa nos permiten concluir la importancia de la escala de la producción de cobre en la zona, con un foco importante en Sierra Morena.

Palabras clave: Alto Guadalquivir, Metalurgia del Cobre, Vértedero, Cultura del Argar, Edad del Bronce.

INTRODUCTION

The complexity of the El Argar society in the Bronze Age of the Iberian Peninsula has been associated to the development of copper metallurgy. The production of this metal now takes a great increase as manifested primarily in the grave goods, among them begin to proliferate weapons. Without going into the debate on the role played by the metal in the social development of these groups (Moreno Onorato and Contreras Cortés 2010; Montero Ruiz and M urillo Barroso 2010; Lull Santiago et al. 2010a), we must say that in Sierra Morena, in specific
geographical areas as the Rumblar and Jándula river basins, the complete mining and metallurgical copper process have been documented. This fact makes this area, the Upper Guadalquivir, a nucleus able to control the extraction and production of copper and, above all, drive its circulation both inside the Argarian territory and in neighbouring areas such as Valencia, La Mancha or Lower Andalusia.

Within the culture of El Argar, the Upper Guadalquivir seems to be the ideal place to carry out a large-scale production because of its proximity to the metalliferous veins of Sierra Morena. Along the valleys descending from Sierra Morena to the Guadalquivir river we found numerous mining and metallurgical villages dated during the early second millennium. They would be exploiting over 400 years the copper ores existing in this area. In one of these valleys, the one of the Rumblar river, is Peñalosa site (Contreras Cortés 2000) (Fig. 1).

![Fig. 1. Location of the Rumblar Valley and Peñalosa site within the territory of El Argar Culture.](image1)

![Fig. 2. Aerial view of Peñalosa with the location of the dump.](image2)
The settlement is located on a hill of slate rock, in a strategic position controlling the Rumblar middle river basin (Baños de la Encina). Their houses are arranged on the slopes of the hill and the whole is defended by a wall with bastions. In almost all areas of the site there have been documented archaeological evidences of copper metallurgy: smelting and melting crucibles, slags, moulds and tools. Several maces and hammers related to mining, crushing ore and forging metal objects were recovered (Moreno Onorato 2000; Moreno Onorato and Contreras Cortés 2010). At the bottom of the village exists a large cistern that collect the rainwater, capable of storing more than 100 m$^3$ of water. This large volume of water leads us to think that would be used not only for human consumption and livestock but also for other activities (Moreno Onorato et al. 2008).

All metallurgical data from Peñalosa published so far were related to the interior of the houses and, above all, with open spaces. However, the picture changed substantially in the campaign of 2010 with the excavation of the Sector 49, outside the wall, allowing to document a slag heap-dump for the first time in a settlement of the Bronze Age in the Iberian Peninsula (Contreras Cortés et al. 2014) (Fig. 2).

THE METALLURGICAL DUMP FROM PEÑALOSA

This deposit of metallurgical wastes is located at the top of the southern slope of the hill, close to the round passage which lies outside the wall and connects the two entrances to the recinct, one at north and the other at south (Contreras Cortés et al. 2014). The floor of this path is made in some sections by tamped earth lying on the natural rock and in others by a cobbled pavement of river pebbles (Fig. 3).

The stratigraphic sequence reveals two filling layers, barely differentiated, which gentle dip from north to south following the direction of the natural slope. These strata, of greyish earth, fine-grained texture and thickness ranging between 1 and 0.15 m, were sealed by a clay layer characterized by the absence of archaeological
material. On the top of this package lies a surface stratum of earth from old excavations (Fig. 4). Archaeological evidence suggests that the landfill was in operation since the foundation of the settlement until the time the pavement of the passageway was built coinciding with the rise and greater extension of the village.

What is important is to note that virtually the entire contents of the dump are metallurgical waste. All the sediment was washed in a flotation machine with different sieves (1 mm and 0.50 mm grid size) to ensure comprehensive collection. Once in the laboratory such materials were washed in an ultrasonic bath prior to proceed to classify them. The last step was to select a representative number of samples that would eventually be analysed under different techniques.

**ARCHAEOMETALLURGICAL CONTENT OF THE DUMP**

The large amount of fragments of metallurgical ceramics recovered in the dump belongs to the typological repertoire already observed in the rest of the site (Moreno Onorato 2000; Cortés Santiago 2007; Moreno Onorato et al. 2010.). Within this group, the highest proportion corresponds to deep crucibles followed by bowl-shaped ones and mould fragments.

Besides ceramic, abundant clay lining fragments from possible combustion structures appear. They are totally different from the ceramics in terms of form, texture, thickness and surface treatment. Now we are dealing with small fragments (1-5 cm) of variable thickness (1-3 cm) that can vary from very straight to much curved form. Often show some finger marks in surface. The clay comes from the supply area located near the site and contains no special temper, which makes it different from the metallurgical ceramics, as discussed below. Most of the lining fragments show a slaggy layer, allowing to be ascribed to metallurgical tasks.

The types of these containers have already been referenced and published (Contreras Cortés and Cámara Serrano 2000; Cortés Santiago 2007; 2010 Moreno Onorato et al. 2010). The optical analysis of their matrices indicate two distinctly different types that can also be subdivided.

![Fig. 4. Part of the dump excavated up to the bed rock and stratigraphic section.](image-url)
into up to a total of four subtypes depending on the mineral that predominates in the temper, its size, the extent it is added and the amount of organic matter detected.

The fabric of the bowl-shaped crucibles (Fig. 5: A and B) is usually coarse in texture, of medium porosity, with abundant rock and mineral temper (quartzite, quartz, feldspar, mica) heterometric in size, being predominant the medium (0.25 - 0.499) and fine (>0 - 0.249) size fractions (Orton et al. 1997; Gámiz Caro et al. 2013). Many of them have pouring spout. The ceramic is highly vitrified in surface by thermal effect, suggesting working temperatures well above 1,100º C.

The fabric of the deep crucibles (Fig. 5: C and D) has as particular feature the intentional addition of vegetal temper. With respect to other fabric matrices, this is a somewhat finer, loamy, very porous and much more lean, with a more homogeneous distribution of tempers. Mineral tempers (quartz, quartzite, feldspar, mica schist and mica) are medium or large-sized (0.5 a 1). Vegetal temper is predominant.

One aspect to highlight of these vessels is that they often present a flat rim with a series of (2-4) semi-circular or oval notches scattered on it. This does not occur in domestic pottery. Sometimes the rim may be bevelled to the inside or, in the case of vessels with less thick walls, to present a sort of central groove. In all three cases these traits could be used to fit a cover. There are also some specimens with rounded rim, regardless of the wall thickness, although they are less numerous. The deep crucibles can also have a pouring spout.

The slaggy layer of these vessels is highly significant. In most of them it tends to be thin, whitish-yellowish-green in colour. In others cases, as in most bowl-shaped crucibles, the slag show a dark colour and a considerable thickness that may even exceed the rims.

Finally, eight fragments belonging to ingot mould have been collected. Their fabric is rude, similar to the one of the bowl-shaped crucibles.

**QUANTIFICATION OF THE DUMP CONTENT (Fig. 6)**

The excavation of this small space (3.95 m³) has allowed the recovery of a large number of metallurgical wastes that can be summarised as follows:

![Fig. 5. Bowl-shaped crucibles (A and B) and deep crucibles (C and D).](image-url)
– 16.2 kg of slag  
– 4 kg minerals, mainly green copper ores but also galena and iron oxide (Fig. 6).  
– 1.771 fragments of deep crucibles (48.6 kg).  
– 98 fragments of bowl-shaped crucibles (1.6 kg).  
– 225 fragments of indeterminate crucibles (1.6 kg).  
– Fragments of 8 moulds (4.1 kg)  
– 34.7 kg of lining fragments (Fig. 6).

COMPARISON OF THE METALLURGICAL DEBRIS OF THE DUMP AND THE VILLAGE (Figs. 7 and 8)

The table 1 shows the weights of the metallurgical residues found in the village (Moreno Onorato 2000) and the ones corresponding to the dump. Considering the global numbers we can conclude that the amount of metallurgical ceramics is similar in both areas while the remains of copper ore are more than twice in the village than in the dump. On the other hand, the amount of slag in the dump is much higher, as expected.

The functional classification of metallurgical ceramics for smelting or melting operations is based on the characteristics of the slag adhering to the wall of the vessel determined in the laboratory. The former usually retain relics of the original ore, and other minerals such as magnetite and leaded compounds have been formed that cannot be properly explained by the composition of the clay (see below).

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<td>48.627,85 gr</td>
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Fig. 6. Quantification of metallurgical ceramic waste in the dump and inside the village.

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Table 1. Weights of metallurgical debris of Peñalosa.

In the preliminary conclusions on the Peñalosa metallurgy was proposed that the deep vessels would be used mainly for melting tasks while the bowl-sized ones would be ore smelting pots (Moreno Onorato et al. 2010: 320). Now, with a higher number of samples analyzed it appears that both types of crucibles were indistinctly used to smelt or to melt, being smelting the prevailing function (Tab. 2). This is quite consistent as more crucibles are needed to produce the metal than to melt it.

THE CERAMIC ANALYSIS: RESULTS

The analytical data of the ceramic matrices allow us to determine its great technological, stylistic and functional similarity. They are ceramic manufactured exclusively for the development of metallurgical tasks.

The material used to make the crucibles is common clay whose composition is shown in the table 3. As can be seen, it is poor in calcium and with an iron content ranging from 2.2 to 8.0%. Some specimens are contaminated by copper salts after their metallurgical usage.
Table 2. Function of the metallurgical ceramic analysed. Percentages calculated within each of the spaces under consideration. It is assumed that each sample belongs to a different crucible.

Table 3. Analysis of metallurgical ceramics (SEM microanalysis; wt. %; nd: not detected).

Fig. 7. Quantification of metallurgical ceramics in the dump and inside the village.
In many cases the outer surfaces of the crucibles readily disintegrate, which is due to a poorly cohesive clay structure suggesting low temperature firing or that the vessel was fired mainly from the inside during the metallurgical process causing an uneven heating of the ceramic body. This will result in weak and easily broken containers (Fig. 9). In other cases the ceramic body matrix shows better quality. The figure 10 is an example. No reaction between temper and clay is observed, but the high porosity suggests gasification of clay compounds that use to occur at temperatures above 1,100 °C. This is probably due to its metallurgical use because the common domestic pottery of the Bronze Age was not usually fired to such a high temperature.

A thick layer of thermal alteration, usually more than one millimetre thick, with large vacuoles, is formed on the inner surface of the smelting crucibles (Fig. 11). Instead, the altered layer is much thinner in the melting pots. The reaction with the ceramic materials is less aggressive (Fig. 12).
Fig. 12. Section of a melting crucible. Note the thin layer of slag (left) on the clay surface. SEM image, backscattered electrons.

ARCHAEOMETALLURGICAL SURVEY

The excavation of the dump has significantly broadened the spectrum of metallurgical debris, more from the quantitative than the qualitative point of view. So far we only had materials removed from the workshops in and outside the huts. Regarding minerals, previous studies determined they come from two different sources, one of copper oxides and carbonates and another of a more complex mineralization in which copper and lead are associated (Moreno Onorato et al. 2010). LIA analyses had identified two mines (Hunt Ortiz et al. 2011) one of which, Mina del Polígono, is rich in this combination of copper-lead ore (Arboledas Matínez and Contreras Cortés 2010).

A wide series of new analysis of materials from the dump have been performed using a pXRF-ED Innov-X Alpha spectrometer, of National Archaeological Museum, operated by Ignacio Montero, and an environmental SEM FeiInspect with detectors of secondary and backscattered electrons and a built Oxford Instruments Analytical analysis system-Inca, of the National Museum of Natural Sciences in Madrid (CSIC), operated by the microscopists L. Tormo and M.M. Furió. These new analyses are in addition to those already previously obtained of samples from the village, which were already disclosed in previous works (Moreno Onorato et al. 2010; Ro-vira Llorens et al. 2015).

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</tbody>
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Table 4. pXRF-ED bulk chemical composition of copper ores from the dump (wt. %; surface analysis; nd.: not detected; LE: light elements).
The table 4 shows the analysis of a selection of minerals from the dump. As can be seen, most are ores with little gangue (small amount of light elements), suggesting that the ore was carefully selected in the mine to prevent the transport of unwanted material. This is also suggested by the absence of residues of ore dressing, both in the villages and in the dump. On the other hand, the fact that among the minerals in the dump predominate the copper-lead associations is telling us that perhaps the dump accumulates metallurgical remains of a period in which they were preferably exploited, probably from Mina del Polígono. This idea is also confirmed by the analysis of slags, being predominant the copper-lead ones, as we will show below.

Comparing the bulk compositions of ores from the huts (Rovira Llorens et al. 2015: 357) and the dump we observe that leaded minerals are predominant in the latter (Fig. 13), as it has been said before.

Previous analyses allowed defining the characteristics of the slags from Peñalosa (Rovira Llorens et al. 2015: 357-359). They can be summarised as follows: immature slags containing plenty of free silica, corresponding to physical and chemical not-in-equilibrium systems resulting of direct reduction of the ore without adding slagging and fluxing minerals. Molten material forms a silicate matrix in which metal prills are embedded. It is common to find remnants of non-reduced original mineral charge and/or its transformation to cuprite, delafossite (if iron oxide is in the gangue) and crystal formations of hedenbergite, melilit, akermanite, wollastonite and other silicates in the series. Fayalite is found in iron-rich slags but the whole product is not a low melting point slag but a conglomerate containing solid and partially fused materials. Another frequent mineral is magnetite, which together with delafossite are good indicators of an environment into the hearth whose oxygen fugacity is variable causing that chemical reactions took place sometimes under reducing conditions and sometimes under oxidizing ones. A good example of this is documented in figure 14, where fayalite and magnetite coexist in the same field of a slag.

These features are found in immature slags well known in Spain and other regions of the Old World since the Chalcolithic period (Rovira Llorens and Renzi 2010; Haupmann 2007), and they are referring to a primitive metallurgy to obtain raw copper using open fires and ceramic vessels as smelting reactors or containers. In these circumstances, the redox conditions of the system are very variable, sometimes oxidizing condition (which encourages the formation of magnetite and delafossite, for example), sometimes achieving reducing conditions to get metal and other compounds, depending on the composition of the charge.

Semiquantitative analysis of bulk composition of slags from the dump and the huts does not show significant differences (Fig. 15), although leaded slags are more frequent in the dump, as could be expected after the study of the minerals.

What really makes original and surprising the Peñalosa metallurgy is the exploitation of copper-lead minerals, undoubtedly abundant in Sierra Morena. The copper-lead slags are
characterized by a complex silicate containing lead as melted material forming the matrix. In some cases almost all the lead goes to the glassy matrix and the metal droplets embedded in de slag contain only small amount of lead id any (Fig. 16). In other samples, however, copper-lead droplets and even metallic lead inclusions are found. When refining the raw copper most of lead reacts with the crucible clay forming a leaded glassy layer (Rovira Llorens et al. 2015: 360-361).

![Fig. 15. Elemental bulk composition of slags from Peñalosa.](image)

As we have said, in many of the metallurgical tasks performed at the site ceramic vessels were used. To decide whether the slag on a sherd has been formed in a process of smelting or melting is simple when relics of primary ores are identified by the SEM analysis: primary ores are not expected to be found in a crucible used to melt metal. But if that is not the case the decision is not so simple because some of the minerals identified in the slag could also be formed by reaction of the metal impurities with the crucible walls and ashes.

There is, however, a subjective argument that can be applied in these cases. While a reduction process is time consuming at high temperature, melting a similar mass of metal requires a much shorter time if the thermal conditions are suitable. The reaction time is an important factor that makes that in the first case the slag layer formed on the ceramic surface is thicker than in a melting crucible. At least that is what is experimentally deduced. In fact in many melting experiments there is no time enough to form slag but a thin glaze layer (Rovira 2012). The criterion applied for classifying the metallurgical ceramics of Peñalosa is based, therefore, on the results of the analysis and, if the results have not been sufficiently conclusive, on the formal aspects of the slagggy layer.

There is, however, an intriguing issue on the Peñalosa metallurgy: what kind of pyrometallurgical structures were used to obtain copper? The excavations of the settlement have not provided any light on the matter. Were they simple fireplaces similar to the domestic hearths? It is likely that the crucibles were stationed in places without special preparation, conveniently surrounded and covered by burning coal. The remains would leave an installation of this type would be an ashy soil with charcoal and perhaps some fragment of ore.

However, among the remains recovered in the dump are small pieces of clay that appear to have been part of the lining of a structure dug into the ground. The prepared surface is smoothed and frequently altered by a slag layer whose composition is similar to the slag on smelting crucibles (Tab. 5). If our interpretation is correct as can be deduced from the analysis, in addition to smelting crucibles simple pits small in size were also used for metal obtaining.

![Fig. 16. Copper-lead slag. Light grey leaded glassy matrix, fayalite (grey) and hedenbergite (black). Crystals and dendrites of magnetite are also visible. White spots of metal. SEM image, backscattered electron.](image)
CONCLUSIONS

The metallurgical debris recovered in the dump from Peñalosa reinforce previous studies that illustrate the primitive nature of mineral processing based on the use of smelting crucibles, a technology that generates little slag after selecting rich copper ores. The recovery of more than 37 kg of lining fragments stresses the importance of using hearts dug in the ground for mineral reduction operations, a method that had not been identified in previous studies of the metallurgical remains of the village. Two kinds of ores were worked: a) copper oxides and carbonates, and b) copper-lead oxides, carbonates and sulphides. These minerals produce two types of dross which compositions are markedly different, suggesting that probably they were not exploited simultaneously. Two mines that provide these ore types have been identified by LIA analysis (Arboledas Martínez and Contreras Cortés 2010; Hunt Ortiz et al. 2011).

The metallurgical ceramics in the dump added to those found in residential areas allow the reconstruction of basic, standardized types, which are designed and made with special technology (types of temper used) exclusively for metallurgical tasks.

The analysis of copper metallurgy in Peñalosa is giving us a series of keys on the importance of this activity in the Bronze Age of the Upper Guadalquivir region and how a large community, both in population and settlements, could support themselves in this space based fundamentally on the metal production.

There are a number of elements that support a large-scale copper production and distribution control. A first indication is the existence of a large settlement in areas like the Rumblar river basin where numerous villages and small pillboxes have been documented (Contreras Cortés 2000; Contreras Cortés and Cámara Serrano 2002). It is a hierarchical settlement, with villages of various sizes that seems to have been established specifically for the metallurgical activity, with mining towns near copper outcrops and metallurgical villages specialized in mineral processing.

A second indication of this large-scale production is the location of 21 prehistoric mines, two in the basin of the Rumblar river (Contreras Cortés et al. 2005; Arboledas Martínez and Contreras Cortés 2010; Arboledas Martínez et al. 2015), one in Linares and 18 in the Jándula-Yeguas valleys, which are discussed in another work of this monograph (Arboledas et al. in press). These mines provide remains of material culture of the Bronze Age, mainly ceramics and stone hammers similar to those found in Peñalosa. In one of them, the mine Jose Martin Palacios (Baños de la Encina) have been documented metallurgical remains (two fragments of smelting crucibles) dated in the Bronze Age (Arboledas Martínez et al. 2015).

In addition, LIA analysis performed on archaeometallurgical material from Peñalosa and several of the mines located in the Rumblar basin relate mines in this valley with the Peñalosa site and even with some copper objects of the El Argar Culture in the Almeria province (Stos-Gale et al 1999).

If the circulation of metal within El Argar territory is still confirmed, the role of the Rumblar basin and Peñalosa could be interpreted in two ways: either we are talking of the most important metallurgical focus of the El Argar State (Lull Santiago et al. 2010b) or we are describing a highly specialized area of this industry, controlled by a few elites established there to control the flow of metal beyond the Upper Guadalquivir region (Moreno Onorato and Contreras Cortés 2010).

Such regional scale production is backed by a singular fact: the manufacture of standardized copper ingots, which as a currency would be distributed by wide territories. In Peñalosa have appeared not only copper ingots (Moreno Onorato 2000) but numerous sandstone moulds to produce them (Contreras Cortés et al. 2010).

In the archaeological record obtained previously, the relatively small amount of archaeometallurgical remains found in the huts and elsewhere in the village could give the impression of a modest, domestic activity. The content of the dump, however, show the great importance of this activity and gives us a more detailed picture of the ore processing in the site. It would be important in the future to determine the entire space occupied by the dump in order to make a more precise quantification this aspect.

Table 5. pXRF-ED bulk chemical composition of the slag layer on clay lining samples from the dump (wt. %; surface analysis; nd.: not detected; LE: light elements).
Peñalosa becomes a unique site to investigate the technological characteristics of the production of copper in the Middle Bronze Age, to assess the role of the metal production and its scale within El Argar Culture, and provides suggestions to reconstruct the social and economic relations of a community located in the south of the Iberian Peninsula.

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