

# Monte Romero, a Silver Producing Workshop of the 7th Century BC in South-West Spain

This paper presents the main conclusions of archaeo-metallurgical research on the excavated material of Monte Romero. The site was first described by Professor Beno Rothenberg in IAMS *Newsletter* Number 9 (1986) p. 1–4. The ancient workshop was dated, on the basis of the archaeological ceramics, to the 7th–6th centuries BC. This corresponds to the time when the Phoenicians founded colonies along the south coast of the Iberian Peninsula and established trading links with the local people. Silver was the commodity that was at the centre of the trade from the Iberian Peninsula to the eastern Mediterranean.

The site of Monte Romero, Site 56, was first discovered in 1975 during the IAMS archaeo-metallurgical survey of south-west Spain directed by Professor B. Rothenberg. It is situated in the precinct of the modern mine of Monte Romero, located in the Sierra Aracena.

The lode of Monte Romero is part of the Iberian Pyrite Belt and as such it is composed of lenses of pyrite and chalcopyrite whose extremities are composed of sphalerite and galena (Fernández Alvarez, 1975: 80). It has to be emphasised that the deposit is extremely complex and ore types tend to overlap in characteristics. However, six principal types of ore have been defined (Fernández Alvarez, 1975: 81). The ore that is believed to have been processed in the ancient workshop is what is called the 'massive complex mineralization' and is composed of coarse crystals of galena and sphalerite with a small quantity of pyrite and quartz. Copper is also present in the form of freibergite  $((\text{Ag,Cu})_{12}(\text{Sb,As})_4\text{S}_{13})$  which may be present at 0.2–0.6%. It is due to the presence of this mineral that both silver and arsenic levels in this type of ore are higher (Fernández Alvarez, 1974: 252). Although this type of mineralization is usually found in deep deposits, at Monte Romero it outcrops to the surface and would have been easily accessible to ancient prospectors and miners.

During the archaeometallurgical survey in this area by Rothenberg and Blanco Freijeiro (1981: 84–7), a scatter of slag, tuyeres, fragments of cupellation dishes and so forth were found at Monte Romero in association with pottery which was initially dated to the 7th–5th centuries B.C. This wide variety of metallurgical finds, the early date of the site and the complexity of the typical ores at Monte Romero convinced the IAMS research group that the site should be excavated.

Two squares labelled A2 and A3 of a total area of c. 50m<sup>2</sup> were excavated in 1986 under the direction of Professor Rothenberg. Differences in the types of metallurgical debris from each excavated square were readily apparent. In Square A2, small slag heaps, discarded furnace wall fragments and straight, slagged tuyeres were uncovered. No furnaces were found *in situ*. The location of these waste heaps, however, suggest that the smelting area was situated directly to the south of the excavation.

Along a low wall in Square A3, a stack of complete, used cupels was discovered (Fig. 1). Furthermore, in

Square A3 bent tuyeres that are not slagged were also found which are believed to have been used in the refining rather than smelting step. It is, therefore, concluded that this area was used for cupellation (Fig. 3). Once again it is believed that what has been excavated is more likely to have been a storage area, while the actual cupellation would have taken place just north of the excavation. A more detailed description of the excavation results and some preliminary ideas on a possible metallurgical process model for the production of silver at the ancient workshop have been published in a previous IAMS Newsletter (Rothenberg *et al.*, 1986).

The material recovered during the excavation has since been the subject of the writer's PhD research undertaken at the Institute of Archaeology, University College London. In this paper, some of the results of the materials investigations and final conclusions are presented.

The excavation of the site has produced two types of slag: tapped slag and 'free-silica' slag. The tapped slag, which had clearly been fluid, is dense and homogeneous. It does not contain any metallic prills visible to the naked eye. In contrast, the second type is extremely inhomogeneous and contains metallic lead visible on a freshly cut surface as well as many large rock inclusions. It does not seem to have ever reached a fully fluid state. This type has usually been called either 'free-silica' slags or 'slag balls'. The names derive from the fact that they contain a large amount of unreacted siliceous rock fragments, as well as having the shape of a ball or a bun.

'Free silica' slag has also been found at other sites located in the south-western part of the Iberian peninsula

Fig. 1. Stack of cupellation dishes as discovered during the excavation of Monte Romero.





which are connected with the extraction of silver (Rothenberg and Blanco Freijeiro, 1981: 99; Fernández Jurado, 1988–1989b: 192). It has been interpreted as a mistake in the smelt (Ruiz Mata and Fernández Jurado, 1986: 260), but this interpretation is unlikely because 'free-silica' slag is now known from many different sites over a wide span of time. Obviously, the same mistake could not have been repeated at all of these sites. Also included among the archaeometallurgical finds from the site was speiss, which is a waste product formed as a separate phase in the presence of an excess of arsenic and/or antimony in the charge. Any process model, therefore, that may be suggested will have to be able to offer an explanation of how and why these slags and speiss were produced.

Used cupels found in the excavation are clear evidence of the cupellation process. The excavation also revealed a quantity of metallic lead whose presence is very significant as part of the process, as it could be either an intermediate product of primary smelting and, therefore, silver rich, or a by-product of the cupellation process and, therefore, de-silvered.

A series of analytic methods were employed for the investigation of these finds. X-ray fluorescence spectrometry (XRF) and inductively coupled plasma (ICP) emission spectrometry were used for the bulk chemical analysis of samples of each of these groups of finds. Since many of the finds were quite inhomogeneous, microanalysis was deemed to be necessary. A microprobe was used to analyse not only the metallic prills trapped in the slag matrix of both the tapped slag and the slag balls but also the different minerals of which the slag is composed. The mineralogical investigation of the slags was supplemented by X-ray diffraction (XRD) analysis. Finally, atomic absorption spectrometry (AAS) was employed for the analysis of the many finds of metallic lead in order to ascertain silver concentrations.

In the survey publication which included Monte Romero, several surface samples of slag from the site were identified as copper smelting tap slags (Rothenberg and Blanco Freijeiro, 1981: 86–7). From the excavation, however, analytical results on tapped slag samples show that the lead concentration is consistently higher than that of the copper concentration (Pb ranging from 2.9% to 5.6% compared to Cu 0.0% to 0.30%). Thus, these new excavated tapped slag samples have been interpreted as lead smelting slags.

The XRF analysis of the tap slags also revealed a relatively high level of barium, averaging 10%. Furthermore, X-ray diffraction analysis of the slag samples indicated celsian ( $\text{BaAl}_2\text{Si}_2\text{O}_8$ ) as the main constituent, not fayalite ( $\text{Fe}_2\text{SiO}_4$ ), one of the most common minerals found in ferrous slags (Bachmann, 1982: 14), as initially expected.

Barite, the barium sulphate mineral, serves as an excellent flux for lead smelting, as it facilitates the desulphuring of galena during the roasting process, while in smelting it reacts with any lead silicates formed, releasing metallic lead (Maréchal, 1985: 30–31). As barite is not commonly found in the argentiferous ores of Monte Romero it is argued here that this property of barite was identified by the ancient metallurgists working at the site and it was deliberately added as a flux to the charge.

As expected, the bulk chemical analysis of the 'free-silica' slag showed a great range in compositions. Some

were silica rich, with  $\text{SiO}_2$  concentrations reaching as high as 50%, some were barium rich with barium concentrations reaching 18%. One sample was found to be manganese rich. Microanalysis of the rock inclusions revealed that the different compositions are mainly due to the presence of different unreacted rock fragments. Thus the silica rich slag balls contained significant amounts of unreacted quartz while the barium rich slag balls contained unreacted barite.

The mineralogy of the slag matrix is regulated by the flux charged. Thus in the barite rich slag balls, celsian ( $\text{BaAl}_2\text{Si}_2\text{O}_8$ ) was the main crystalline phase. In contrast, in the silica rich slag balls, hedenbergite ( $\text{CaFeSi}_2\text{O}_6$ ) and anorthite ( $\text{CaAl}_2\text{Si}_2\text{O}_8$ ) were the main minerals. It seems, therefore, reaction had taken place between the ore and the flux which led to the formation of these silicates. This was then followed by the introduction of excess flux which did not have the opportunity to react fully and is, therefore, found in the form of these large inclusions.

In general, this 'free-silica' slag has a very high lead concentration averaging c. 10% Pb, but sometimes reaching as high as 25%. Microanalysis of a number of samples showed that the lead is in the form of entrapped metallic prills as well as lead silicate glass which is the matrix component of the slag. The prills can often be observed with the naked eye in a fresh break.

A number of hypotheses have been proposed for the 'free-silica' slags. In the *IAMS Newsletter* (1986) publication of Monte Romero, it was suggested that the free-silica slags were the product of the recycling of the cupels and furnace linings and that the rock inclusions acted as a 'sieve' which facilitated the separation of the lead metal from the slag. Professor Tylecote, on the other hand, had suggested that the quartz crystals were used as a means of solidifying the slag and absorbing it as a sponge thus enabling the separation of the metal from the slag (Tylecote, 1987: 306–7).

Historically, metallurgical activities from the middle of the last century add another perspective to possible interpretations of the free-silica slag. Percy describes a lead smelting process where lime is added to the molten charge of the furnace in order to stiffen the molten charge which is subsequently cooled and remelted with more lime. According to Percy (1870: 230) in the final stages of the smelt: 'Lime is again added, the slag is pushed back from the surface of the lead and left to drain a little, the lead is tapped out and the slag is then raked out of the furnace in pasty lumps termed 'grey slag'.

The use of the lime, Percy argued, is purely mechanical, in other words to cool and solidify the slag. The removal of the slag as a solid enabled the lead metal to be exposed to the atmosphere of the furnace and thus further reactions took place. Furthermore, any lead trapped in the slag has the time to drain off and to be collected (op. cit: 236–8).

It is suggested for the archaeometallurgical remains from Monte Romero that the free-silica type of slag was the result of a similar process, where silica and barite were used in a similar way. The charge was saturated with an excess of flux in the form of quartz and barite. As a result the slag cooled and solidified, thus enabling its separation from the lead metal. The presence of a large amount of glass as well as the quenched form of the crystals in the matrix support the idea that the slag was rapidly cooled.



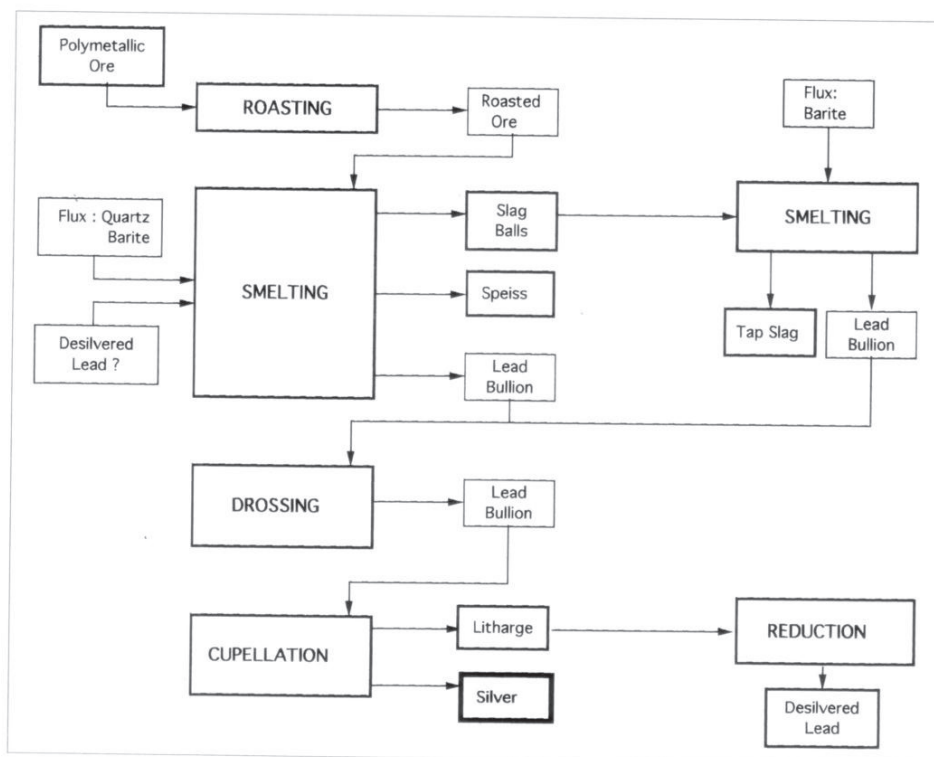


Fig. 2. Process model for the smelting of polymetallic complex ores and recovery of silver through cupellation at Monte Romero.

The fact that the slag balls contain so much lead, combined with the fact that a large group of complete balls was found stored in a pit in Square A3 (Locus 16) together, suggests that the free-silica slags were to be retreated at a subsequent step in the overall process. The tapped slags in contrast to the slag balls do not contain lead silicates. This suggests that the 'free silica' slag was charged back into the furnace mixed with more barite flux which has reacted with the lead silicates, releasing the lead and forming a more fluid slag; the tapped slag.

The furnace wall fragments from the site commonly consisted of a layer of slag adhering to a layer of clay which was smeared over the furnace wall construction: slate plates alternating with clay. Based upon the curvature of the largest furnace wall fragment, the approximate diameter of the furnaces was only 24cm. XRF analysis of the furnace lining found this to have a higher  $\text{SiO}_2$  content than the tapped slag and a very high lead content (ranging between 16.2 to 22.4%). The compositional results of the furnace lining agrees with observations drawn from the study of examples produced during experimental smelting work (Merkel, 1990: 119, note 15; Hetherington, 1978: 203). Microanalysis of the furnace lining found the lead to be present in the form of lead silicate within which some celsian crystals were formed. This detail clearly matches the furnace fragments from where the sample was taken to the production of the tapped slag or perhaps the barium rich-slag balls.

Microanalysis of a slagged tuyere also detected barium in the slagging which was mainly composed of lead silicate. This matches the straight tuyere fragments to smelting operations through the presence of barium rich slag. The analysis of a drop attached to a bent tuyere, which was not slagged, found this to be composed predominantly of lead oxide. This indicates that the bent tuyere had once been in contact with litharge or metallic lead, and as such would connect this find to the cupellation process.

The XRF analysis of the speiss found this to be mainly composed of copper (average = 31%), antimony (average = 17%) lead (average = 26.36%) iron (average = 9%) and arsenic (average = 4%). The speiss was also found to contain 0.5% of silver. Although, a model for the desilvering of speiss has been suggested by Craddock et al. (1987: 10), such a process does not seem to have been undertaken at Monte Romero. The presence of speiss at Monte Romero is not surprising considering the mineralogy of the complex ore used. An excess of antimony and arsenic would have existed in the charge due to the presence of freibergite in the ore.

Metallic lead was found at Monte Romero in the form of large flows with a ropy surface as well as small droplets. Analysis of all of the lead finds by AAS revealed that some of the lead samples were silver-rich, while others have a silver concentration lower than 1,000ppm. The analytical results showed that, indeed, there existed specimens of silver-rich lead (with silver concentrations of 5,000ppm) as well as desilvered lead (with silver contents as low as 100ppm) at the site. The desilvered lead probably derives from recycled litharge and used cupels. In terms of silver concentration and size, most of the finds which had a concentration of silver between 3,000 and 5,000ppm are small droplets, while the majority of large pieces contain about 1,000ppm of silver.

Most of the lead samples, complete cupellation dishes and the fragments of the cupellation dishes came from a single pit located near the low wall in Square A3. Analysis of the cupels showed that these were almost completely composed of lead oxide ( $\text{PbO}$  c. 80%). It is therefore assumed that these were stored there awaiting to be reprocessed. As the lead was stored in the same pit, it seems likely that the lead and the cupels were meant to be reprocessed together. As both silver-rich and desilvered lead were found mixed together, and as it seems to have been impossible to readily distinguish between the two by eye, it is suggested here that all of the contents of



the pit were meant to be added to the smelting charge in order to assist in the formation of the silver-rich lead bullion.

The model (Fig. 2) proposed for the Monte Romero finds may seem rather complex for such an early archaeological period. Nevertheless, it does agree best with the archaeometallurgical evidence from the site. The polymetallic ore would have initially been roasted to drive off a portion of the sulphur. Next it was mixed with quartz and barite flux and charcoal, then charged into the smelting furnace. The products of this smelting step would have been slag, speiss and lead, probably present in three superimposed layers in the furnace. However, separation of these three distinct layers would have been difficult at this step of the process. Thus, rather than being tapped, the slag was cooled and solidified by the addition of large inclusions of crushed rock and removed in the form of these slag balls.

The speiss and lead would have been left in the furnace, where upon cooling, speiss having a higher melting point than lead, would have solidified and could be removed in the form of plates. The primary lead could then be tapped out. The lead produced would have been silver-rich and would subsequently undergo cupellation.

The slag balls, however, still contain a large amount of lead and, therefore, would have been re-treated. They could be crushed and mixed with more barite flux and charged back into the smelting furnace. The barite would react with the lead silicates releasing metallic lead and forming a fluid tap slag. Any trapped metallic prills would also be released and liquefy to the bottom of the furnace. Thus this cycle would produce a tap slag and more metallic lead.

The presence of slagged crucible fragments from the site, whose analysis revealed that the slag was in fact layers of lead metal with a mixture of copper and antimony, may be evidence of a drossing step previous to cupellation. In 'drossing' the lead metal is melted, due to the low solubility of the other impurities in molten lead and their lower specific gravity, they float to the surface from where they can be removed. This produces a more refined, silver-rich, lead which would then be cupelled.

Cupellation took place in cupels with an average diameter of 12cm. Although the best material for the manufacture of cupels and cupellation hearths is traditionally known to be bone ash, this was not used in the preparation of the cupels from Monte Romero. XRF analysis of the cupels does not detect any phosphorus. The products would be silver, which has not been found in the site, and litharge, the lead oxide. The cupels found at Monte Romero are completely saturated with litharge.

The fact that much of the lead that does not contain much silver indicates that the litharge was reduced in a

final step to produce metallic lead. It seems likely that this was again recycled into the smelting furnace where it would again act as a collector of the silver from the polymetallic ore.

The site of Monte Romero offers a unique opportunity to investigate a silver workshop of this period. Unlike other workshops that have been excavated, such as that at San Bartolomé de Almonte (Ruiz Mata and Fernández Jurado, 1986), Monte Romero is located in close proximity to the mine and shows all the various steps of the process, from the ore to the cupellation. Also, unlike larger sites, such as Rio Tinto, Monte Romero was occupied only during a single period, which avoids the complex stratigraphic problems of mixed finds belonging to different processes of different periods.

The sophisticated process established by our archaeometallurgical investigation, shows that the people working in the 7th century B.C. workshop of Monte Romero were competent metallurgists who were able to process even highly complex ores to produce silver.

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# Bronze and Iron Age Metallurgy from the Oman Peninsula

Most research concerning collections of ancient metalwork is approached from either a purely analytical or typological viewpoint. In this work, an attempt has been made to combine both approaches. The copper alloy weapons have been investigated using atomic absorption spectroscopy, standard metallographic techniques and

scanning electron microscopy with energy dispersive microanalysis. Typological comparisons are made to other metal object finds at sites in the region. The material that forms the corpus of the study, on loan for analysis and conservation from the Al Ain Museum in Abu Dhabi, comprise grave finds from three sites in the