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Archaeometallurgical characterization of Late Antique personal adornments. The necropolis of Cortijo del Chopo (Granada, Spain)

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ABSTRACT

Objects of personal adornment from Late Antiquity have been extensively studied in the Iberian Peninsula since the 19th century, when the first funerary contexts from that period began to come to light. However, only partial information was available with regard to their production process and chemical composition. This came from the archaeometallurgical studies carried out on funerary assemblages from central and northern Iberia. In order to obtain a more complete picture, a set of 80 copper-based alloy objects were analysed, most of ornaments and parts of them, from the necropolis of Cortijo del Chopo (Granada), in southeastern Spain. The results from the portable X-ray fluorescence reveal the presence of a wide variety of alloys and confirm the practice of recycling metals to make the items, a characteristic of the metallurgy of the period. Lead isotope analysis provide evidence of a local production of brass objects with a high Zn content, similar in appearance to gold.

1. Introduction

It is evident that dress accessories played an important role in identity construction during Late Antiquity and it is of special interest to study it in detail. To this effect, numerous studies have been undertaken on the Iberian Peninsula since the beginning of the 20th century (Götze, 1907; Åberg, 1922; Zeiss, 1934, 1936; Reinhart, 1947; Palol, 1950). Ripoll's research (1985, 1991, 1993, 1998) renewed our knowledge of the funerary archaeology and personal adornments of the Visigothic period. More recently, various authors (e.g. Barroso Cabrera and Morín de Pablos, 2006; Balmaseda Muncharaz, 2008; Pinar Gil, 2012; Kazanski et al., 2022) have approached the study of the ornaments and the population in question from different perspectives.

In this respect, archaeometallurgy has made major contributions to the investigation of these finds. The first analyses carried out on items of personal adornment from the 5th-7th centuries AD on the Iberian Peninsula were developed in the 1980 s. The first one was the study of the necropolis of El Carpio de Tajo (Toledo). It was requested by Ripoll with the intention of undertaking multidisciplinary research that would contribute the greatest possible amount of information about the Visigothic period based on the assemblage of objects from that site (Ripoll, 1985). This was a starting point for the successive studies of Late Antiquity that have been carried out in the last forty years. The year 1982 saw the beginning of the "Archaeometallurgy of the Iberian Peninsula" project, aimed at studying metallurgical technology during prehistory and increasing the existing data in the country. Approximately 24.000 X-ray fluorescence (XRF) composition analyses and 900 metallography studies were carried out (Rovira Llorens and Montero Ruiz, 2018), making it the project that has examined the largest number of objects on the Iberian Peninsula. Despite its interest in the first metallurgy, analyses were also carried out on a wide variety of finds from different chronological periods, including a total of 618 pieces from Late Antiquity (Rovira Llorens and Montero Ruiz, 2018). Since the 1980 s, the number of studies of archaeological metals from the period in question incorporating archaeometallurgical analysis has increased. However, the objectives pursued and the type of technique used has differed. Furthermore, due to challenges deriving from the state of preservation of the pieces and the legislation protecting them, a large part of the analyses of this period were carried out on their patina and not on the metal core. This is a stumbling block when comparing the

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different assemblages examined.

More than 500 copper-based finds from Late Antiquity were analysed, the vast majority of them being adornments from funerary contexts[1] (Rovira Llorens, 2017), although some still remain unpublished. The Meseta region, specifically the area close to the Central System, is that with the largest number of dress fasteners and accessories analysed; they come from ten necropolises (Rovira Llorens and Sanz Nájera, 1985; Rovira Llorens et al., 1989; An unpublished report, 1988–89; Ballester, 1995; Blasco Bosqued and Gómez Ramos, 2001; López Requena and Barroso Cabrera, 1994; Montero Ruiz, 1996, 2017; Morín de Pablos et al., 2006; Rovira Lorens, 2017; Ardanaz Arranz, 2000; Gutiérrez Neira et al., 2014). To this geographical area we can add approximately 60 analysed materials from the north of the Iberian System (Tejado Sebastián, 2010), an area close to the Cantabrian Mountains (Gutiérrez Cuenca and Hierro Gárate, 2021), and the Basque Mountains (Azkarate, 1999), as well as the southeast of the Peninsula (Pascual Martínez, 2016) and Portugal (Cardoso et al., 1995) (Fig. 1). In addition, various ornaments of unknown origin have been analysed (Rovira Llorens, 1987; Ballester Gómez, 2019, 2020).

According to Rovira Llorens, 2017, the feature that characterises Late Antiquity metallurgy in Iberia is the wide variety of alloys used in the manufacture of the objects, among which are ternary Cu-Sn-Pb and quaternary Cu-Sn-Pb-Zn alloys. Brasses occupy a prominent place, while Cu-Sn binary bronze pieces are relatively scarce (Rovira Llorens et al., 1989). Montero Ruiz and Orejas (2018) have also delved into Iberian metallurgy with a comparative analysis between the practices of Hispania and Britain (Pollard et al., 2015). In concrete figures, with respect to the early Imperial period, in Late Antiquity Hispania there was a slight increase in the presence of brass and leaded brass (26 %), as well as in quaternary alloys (30 %). In Anglo-Saxon metallurgy, in contrast, this last type of alloy predominates (75 %) and the minimum amount of brasses and leaded brasses is noteworthy (1.3 %). The differences are also notable in terms of the proportion of impurities present in the metals and alloys used in both areas (Montero Ruiz and Orejas, 2018) therefore suggesting different metallurgical traditions.

In this paper we present the X-ray fluorescence (pXRF) and lead isotope analyses carried out on finds from Cortijo del Chopo necropolis with the aim of contributing to our knowledge of metallurgical practices on the Iberian Peninsula. This information is contrasted with the results from the centre of the Peninsula in order to evaluate the possible regional metallurgical traditions.

2. The necropolis of Cortijo del Chopo (Colomera, Granada)

Cortijo del Chopo necropolis is located in the southwestern part of the Montes Orientales (Eastern Mountains), close to the Vega de Granada plain (Fig. 1) (Pérez Torres and Toro Moyano, 1990; Pérez Torres et al., 1987, 1992).

Excavations were carried out in the cemetery in 1986, 1988 and 1989, during which 168 graves were identified and excavated (Fig. 2). Most of these are cists and successive burials are frequent (Pérez Torres et al., 1987, 1992). However, due to the urgency of the work, the data obtained in the last two campaigns has remained unpublished.

Grave goods were identified in 50 % of the funerary structures in the necropolis. Specifically, 22 % of the tombs contained metallic objects, mostly copper-based pieces (17 %) (Fig. 2 and Supplementary Material) and/or iron (6 %), as well as pottery (37 %) (although some fragments could not be located). In addition, charcoal and wood remains were found in 3 % of the graves. Regarding only the items that formed part of the attire, 17 % of the tombs contained metal adornments and 5 % non-metallic ones (glass paste and amber beads). Many structures were found to be in a poorly preserved state and some had been partially or wholly looted. Based on the available data, we highlight the importance of two tombs in the central-western part of the cemetery (Nos. 45 and 47). They contained a high concentration of dress accessories –26 pieces (composed of ca. 36 elements and ca. 140 beads)– compared to the rest that only contained a couple of ornaments.

The necropolis presents a chronology between the late 5th and the early 8th centuries. Radiocarbon analysis was carried out on four graves containing copper-based alloy materials analysed for this study (Table 1).

3. Metal artefacts

An assemblage of 100 objects was documented at Cortijo del Chopo necropolis (Granada), mostly finger rings (22), earrings (14), bracelets (6), belt components (6), pins (49) and some pieces of undetermined use (3). Likewise, numerous elements that would have formed part of such adornments were identified, including finger ring settings (6), settings and “baskets” (7) and small hoops (4) for earrings, several pin fragments and 1 pin setting, which increased the number of copper-based objects found in the necropolis to ca. 118. A possible knife, 5 bracelets and 4 buckles, all made of iron, as well as 19 undetermined iron artefacts were also identified.

3.1. *Finger rings*

The documented rings are divided into three typological groups. Firstly, those that consist of a shank with a variable section and a bezel-set stone (Fig. 3a), most of which have a rectangular section, with the exception of one that is circular. These make up 50 % of the rings. The second group is represented by the rings of varied monometallic shapes that are completely closed with an oval or circular section (Fig. 3b, c). The third includes the open-shaped ones with a filiform or rectangular section, with part of the surface decorated and ends that overlap to close (Fig. 3d).

3.2. *Earrings*

All the earrings are hoop-shaped. Two main types can be distinguished by their formal characteristics. The first, with a single specimen, has a flat section and a simple hook closure[2] (Fig. 3e). The second includes earrings with a threadlike hoop and a circular section that gradually loses thickness until one end finishes in a point; the other end is blunt. In this group, up to four models can be distinguished. There are specimens with incised decoration on the non-pointed end of the ring itself; those with a plate that covers the upper end of the ring as a moulded head (Fig. 3f); those with two mouldings (Fig. 3g); and the basket earrings. Regarding the last of these, the pieces from Cortijo del Chopo present parallels, although simpler, with the forms of the Italic tradition dated between the end of the 6th and the 7th centuries AD (Possenti, 1994). No complete earrings have been found, but openwork peripheral baskets have been identified, as well as small hoops and settings (Fig. 3h) that indicate the presence of at least two variants, one with an openwork basket and the other without.

3.3. *Bracelets*

Six bracelets have been documented of which two types can be distinguished. The first type consists of five penannular pieces, four of which have a circular section that ends with incisions (Fig. 3i), while another is oval in section and has no decoration. The second group corresponds to a single specimen of a completely closed shape with intertwined ends forming a closure of two knotted threads, and whose

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[1] These have been carried out mainly on materials from the necropolis of El Carpio de Tajo, Camino de los Afligidos, Cacera de las Ranas and Castiltierra, dated around the 5th and 7th centuries AD.

[2] This piece (DJ00112) could also correspond to a child’s bracelet.

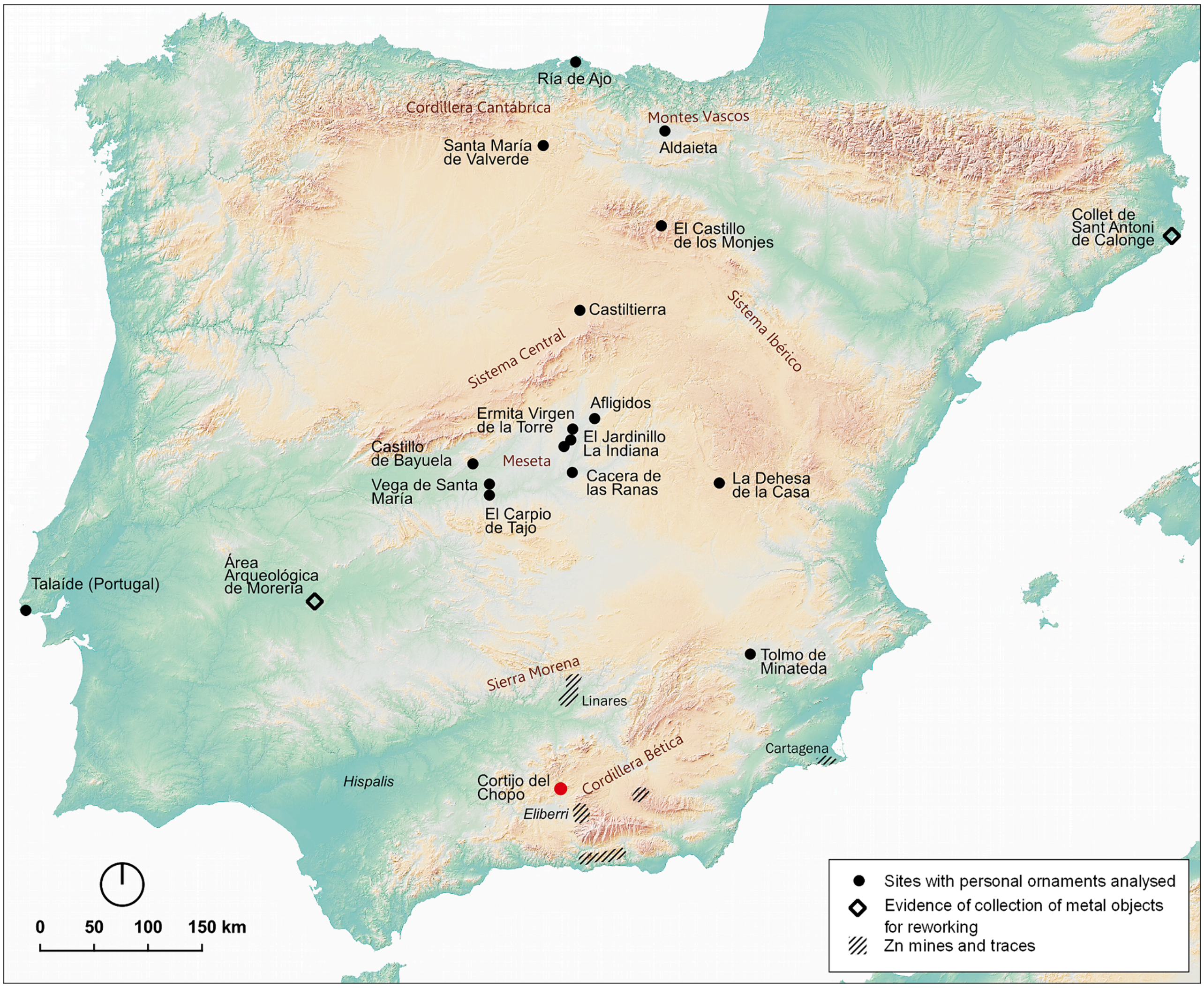

Fig. 1. Location of the necropolis of Cortijo del Chopo (Colomera, Granada) and other sites on the Iberian Peninsula mentioned in the text. Images of the relief © Servicio de Cartografía de la Universidad Autónoma de Madrid.

surface presents incised zigzag lines (Fig. 3j). Also found were iron fragments of various sizes in shapes with a circular tendency and identified as bracelets (5 specimens).

3.4. *Belt components*

Regarding the elements that formed part of belts, several pieces with different characteristics have been documented. A lyriform belt buckle that could be part of Ripoll's G1 group (Ripoll, 1998) (Fig. 4k), a kidney-shaped buckle (Fig. 4l), another smaller rectangular buckle (Fig. 4m), and three rectangular plates that present a decoration of opposing triangles (Fig. 4n). Due to their morphology, the latter are transversal decorative appliques like those of the large belts of late Roman tradition, dating from the second half of the 5th century AD (Pinar Gil, 2012) and may have had a longer duration over time (Salinero Sánchez, 2021). Furthermore, four iron buckles were identified.

3.5. *Pins*

In total, 49 *aci* and various fragments were excavated. In general, they have a rectilinear or fusiform stem and a circular section. Most of them still have the pointed end and the head can be simple, spherical, prismatic or pyramidal (Pérez Torres et al., 1992) and set in a hemispherical bezel with cabochon.

3.6. *Other metallic objects*

Some indeterminate objects have also been documented, including a ring (Fig. 4p) that could have been part of a chain or used to hold a knife, an elongated blade, and a shapeless piece of metal. Due to their characteristics, indeterminate iron artefacts were also found in the necropolis –one in the form of a knife and 19 fragments of variable shapes and dimensions– it is unknown whether they would have functioned as part of the attire or as tools.

4. Materials and methods

An assemblage of 78 copper-based objects (ca. 66 % of the total documented) was analysed for its elemental composition, including 22 finger rings (100 %), 4 ring settings (66 %), 14 earrings (100 %), 6 earring settings and "baskets" (85 %), 3 small hoops (75 %), 5 bracelets (83 %), 4 belt components (66 %), 16 pins and 1 pin setting (34 %), and 3 indeterminate objects (100 %), as well as two small plates that enveloped the hoop of two earrings. All the bracelets were analysed but due to difficulties on patina removal on one of them (DJ00116) high levels of not alloying elements were detected and therefore results on this sample were considered unreliable and not measured. The remaining objects could not be analysed because they were recently recovered during the subsequent anthropological study. In the case of

Fig. 2. Plan of the necropolis of Cortijo del Chopo (Colomera, Granada) with indication of the graves with copper-based alloy objects analysed.

the pins, due to the high number of them (49 and fragments) a selection of pieces was made.

Elemental composition analysis was conducted using a portable Niton XL3T-950 GOLD X-Ray fluorescence (pXRF) spectrometry analyser with an Ag-anode from the Antonio Arribas Palau Archaeometry Laboratory of the University of Granada Department of Prehistory and Archaeology. The finds were analysed at the Archaeology and Ethnology Museum of Granada by mechanically removing the patina and corrosion from the surface. Measurements were conducted using the ‘general metals’ analytical mode especially optimised for the mentioned department to analyse archaeological metals. A collimated beam of 3 mm, 35 KV voltage and 20 μA current was used with an acquisition time

Table 1
^{14}C dates of Cortijo del Chopo. All samples were dated at the Scottish Universities Environmental Research Centre (SUERC).

Laboratory Code	Type of bone	Tomb	Radiocarbon age (BP)	δ13 IRMS ‰	δ15N ‰	C:N	%C	%N	Calibrate date (68 % confidence) cal AD	Calibrate date (95 % confidence) cal AD
SUERC-122984	Left Femur Individual 1	47	1499 ± 24	−19.0	8.3	3.2	34.7	12.6	560–600	542–639
SUERC-122988	Left Femur Individual 2	47	1432 ± 21	−19.1	8.9	3.2	36.6	13.2	606–646	598–652
SUERC-122989	Left Ulna	45	1433 ± 21	−19.0	8.9	3.3	38.5	13.7	606–645	597–652
SUERC-122990	Cranium	94	1402 ± 24	−18.8	10.6	3.2	39.5	14.2	610–657	605–661
SUERC-122991	Cranium	73	1334 ± 24	−19.4	8.3	3.4	28.6	9.9	655–759	650–774

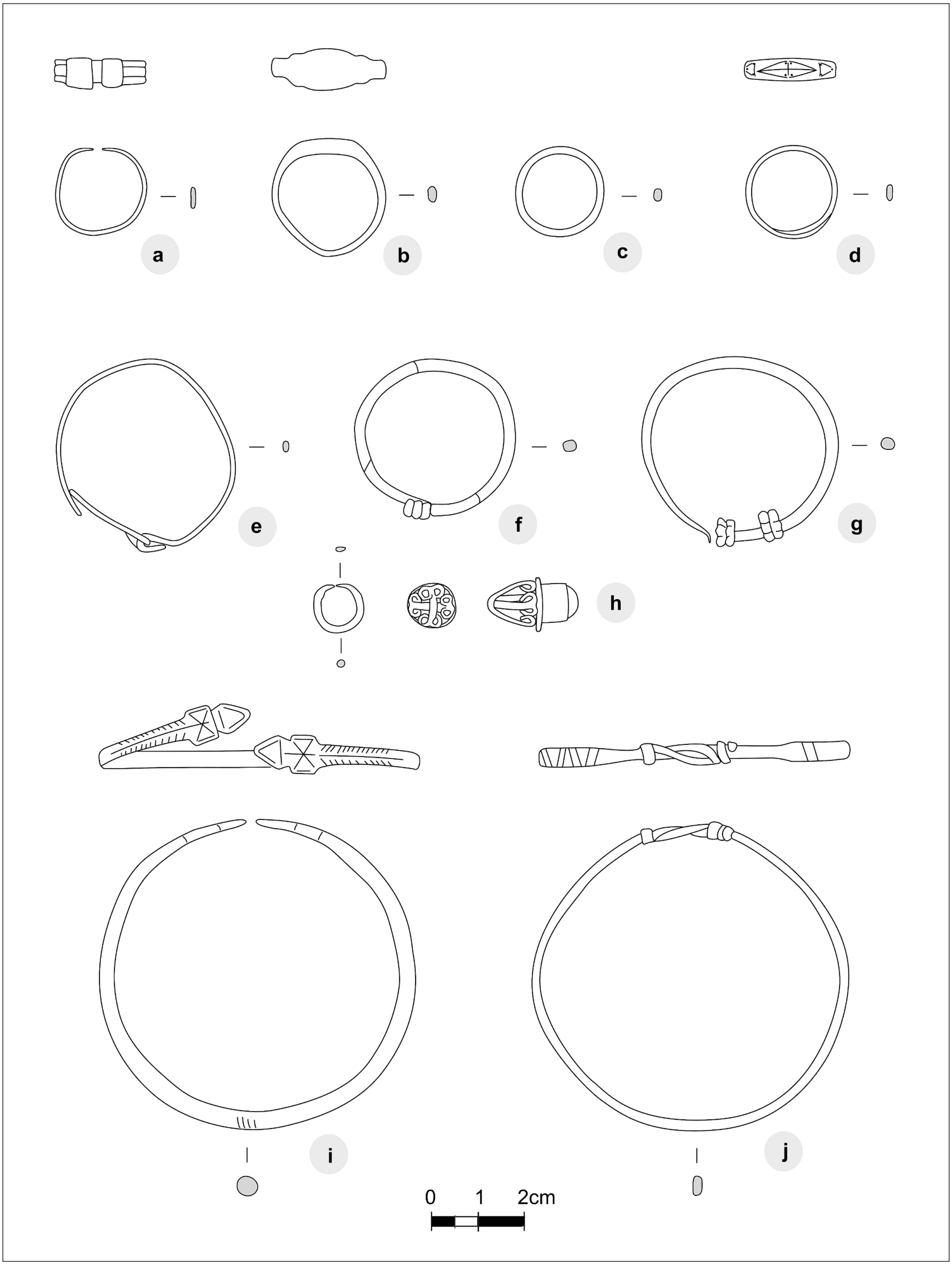

Fig. 3. Some personal adornments analysed from Cortijo del Chopo necropolis: finger rings (**a-d**), earrings and parts of basket earrings (**e-h**) and bracelets (**i-j**).

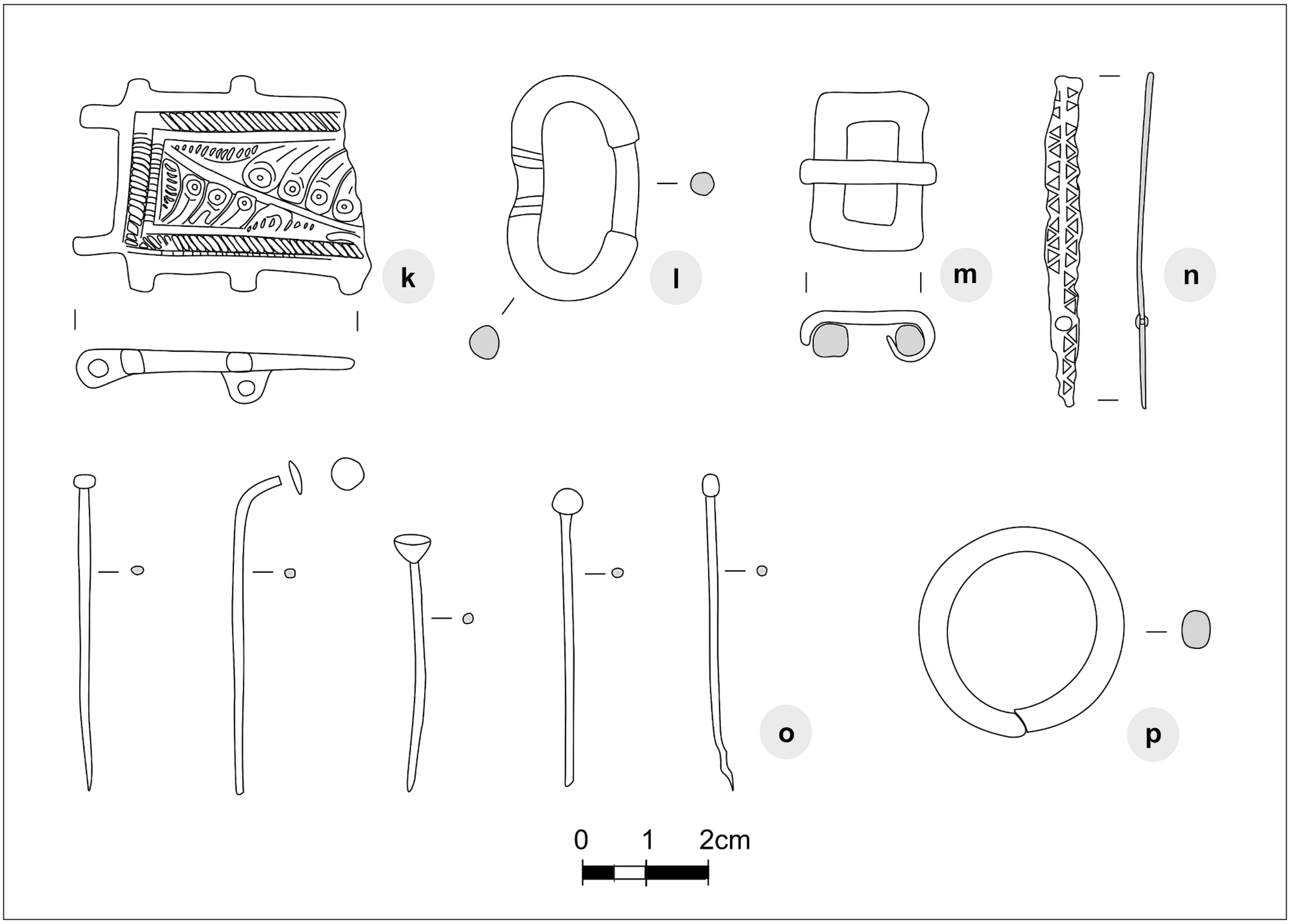

Fig. 4. Some objects analysed from Cortijo del Chopo necropolis: belt components (**k-n**), pins (**o**) and a ring (**p**).

of 60 s, with detection limits on Cu-based alloys of 70 ppm Sb and Sn, 30 ppm Bi, 35 ppm Pb, 220 ppm Zn and 110 ppm Ni and Co. The bronze standards BNFC50.03. and 2371.106-UZ51, were used to monitor the reliability of the analyses (Table 2).

Seven samples (see Supplementary Material) were selected for further lead isotope analysis (LIA) at the Geochronology and Geochemistry Service (SGIker) of the University of the Basque Country (Spain). LIA was conducted using a multi-collector inductively-coupled plasma mass spectrometer (MC-ICP-MS) following the methodology described in Rodríguez et al. (2020).

Aliquots of 0.05 g of the samples were prepared and dissolved in 0.5 mL of 7 N HNO3 overnight on a 70 °C heating plate. After the digestion and evaporation of the liquid, the residues were re-dissolved in 0.5 N HBr and processed by conventional liquid chromatography with an AG1-X8 ion exchange resin (Manhès, 1982), obtaining final solutions of 2 mL of 6 N HCl with the purified Pb. These solutions were taken to

Table 2
Copper-based standards BNFC50.03. and 2371.106-UZ51 used to control the reliability of the analyses performed.

Sample	Sb	Sn	Pb	As	Zn	Cu	Ni	Fe
2371–106 uz51-1		1.62	0.25	0.09	14.31	83.36	0.18	0.10
2371–106 uz51-2		1.63	0.23	0.08	14.41	83.30	0.17	0.10
2371–106 uz51-3		1.63	0.24	0.10	14.41	83.28	0.17	0.09
2371–106 uz51-4		1.61	0.24	0.08	14.36	83.35	0.16	0.09
2371–106 uz51-5		1.63	0.25	0.06	14.36	83.38	0.15	0.09
Average		1.63	0.24	0.08	14.37	83.33	0.16	0.09
Standard		1.52	0.19	0.09	14.40	83.52	0.15	0.10
Absolute Difference		−0.11	−0.05	0.01	0.03	0.19	−0.01	0.01
Relative difference (%)		−6.93	−26.00	6.12	0.21	0.22	−9.73	8.40
Sample	**Sb**	**Sn**	**Pb**	**As**	**Zn**	**Cu**	**Ni**	**Fe**
bnf c.50.03–1	0.20	8.44	8.44	nd	1.48	78.75	2.51	nd
bnf c.50.03–2	0.17	8.44	8.44	nd	1.54	78.77	2.44	nd
bnf c.50.03–3	0.19	8.37	8.28	nd	1.52	79.03	2.44	nd
bnf c.50.03–4	0.17	8.39	8.46	nd	1.54	78.79	2.53	nd
Average	0.18	8.41	8.40		1.52	78.83	2.48	
Standard	0.20	8.50	8.70	0.10	1.45	78.62	2.28	0.01
Absolute Difference	0.02	0.09	0.30		−0.07	−0.21	−0.20	
Relative difference (%)	9.88	1.08	3.40		−4.78	−0.27	−8.86	

dryness.

The lead samples were dissolved in 1.5 mL of 0.32 N HNO3 and if necessary diluted to a final concentration of 150–200 ng Pb/g solution. They were then introduced as wet aerosols in a Neptune (Thermo Fisher Scientific) MC-ICP-MS using a PFA micro-nebuliser with nominal suction of 100 μL/min (Elemental Scientific) and a double pass dual cyclone-Scott expansion chamber. Actual baselines (electronics + chemistry) were subtracted from the measurements of a chemical blank for 60 s prior to each sample. The spectrometric measurements were carried out in 105 cycles with an integration time of 8 s per cycle.

A Thallium reference material NBS997 with a normalised ratio of 205Tl/203Tl = 2.3889 was used for the internal mass correction (see Chernyshev et al., 2007 and references therein for further methodological detail). The reliability and reproducibility of the method were verified by regular measurements of the certified reference material NBS981 interspersed between the measurements of the samples and in the same conditions. The average uncertainties (2SE) for the NBS981 during this study were 0.0004 for the ^{206}Pb/^{204}Pb ratio, 0.0005 for the ^{207}Pb/^{204}Pb, 0.0014 for the ^{208}Pb/^{204}Pb, 0.0001 for the ^{208}Pb/^{206}Pb and 0.00003 for the ^{207}Pb/^{206}Pb (the NBS981 values used were those proposed by Baker et al., 2004). Measurement uncertainties are smaller than the symbols used in all graphs.

5. Results

5.1. Elemental composition

The compositional analysis results show a wide variety of alloying elements, with a considerable variability in Pb (up to 14.1 %), Sn (up to 21.1 %) and Zn (up to 23.6 %) contents as well as impurities of Ni (up to 0.76 %), As (up to 1.4 %), Sb (up to 2.65 %) Ag (up to 1.19 %) and Fe (up to 1.97 %) (Table 3). Only 6 small pins (7.5 % of the analysed assemblage) can be classified as copper (Sn, Pb and Zn <2 %). For the classification of the copper-based alloys, several authors have considered different thresholds for the alloying elements. Pollard et al. (2015) has used a cut-off value of 1 % for tin. Gaudenzi and Martinón-Torres (2016) and Rovira Llorens, 2017 have chosen a value of 2 %. Although these limits are arbitrary, we followed the classification criteria applied by those last scholars, as 2 % is high enough to exclude the natural contributions of Zn, Pb or Sn from the copper ore itself. However, with the view that the concentration of particular alloying elements in a specific object depends on its life history, this threshold may be somewhat artificial when dealing with recycled metal (as discussed below) and the presence of low amounts of an alloying element may be more the result of metal recycle rather than the explicit intentionality of producing an alloy. This could be the case of the ring setting DJ00144 with 2.65 % Sb, in which Sb was not considered an alloying element.

In the analysed finds from Cortijo del Chopo, the predominant type of alloy was brass (28.7 %) with a Zn content always over 8.75 % (Table 4, Fig. 5). The objects made with this alloy, mainly earrings (34.7 %), present an increasing tin content ranging from undetected levels to as much as 2 %, the limit we set to establish the gunmetal classification. This would be the next most common alloy (18.7 % of the pieces), in which the Sn levels also show an increasing trend from 2.05 to 5.92 % Sn. However, the high Zn content found in gunmetal is striking, ranging from 6.77 % to 18.1 % Zn. Most of the finger rings were made from this alloy (46.6 %).

In the bronzes (16.2 % of the pieces analysed), we have two groups differentiated by their Sn levels: a minority group of bronzes poor in Sn (≤3.3 % Sn), composed of four small pins, and another of bronzes with levels of ≥6.98 % Sn. Most of the pins with low Sn content and the finger rings were made of bronze (38.4 % in both cases). As exceptions, due to their high percentage of tin, two rings with Sn values of 18.1 % and 21.2 % stand out. No leaded coppers have been documented in the materials analysed.

Thus, two different patterns appear to be observed in the Cortijo del Chopo metal assemblage when comparing Zn and Sn levels. While the bronzes show an increasing tendency in Sn levels ranging from 2.29 % to 11.7 %, the brasses do not show values of less than 8.75 % Zn, and when they do, they are found alloyed with Sn or Pb. This disparate trend seems to reflect a greater recycling of bronze objects with subsequent tin losses, and a primary production of brasses that, in the case of reuse, are alloyed with Sn or Pb (Fig. 5).

Lead is also found in different alloys, mostly in leaded bronze and leaded gunmetal (12.5 % of the total finds analysed in both cases). Only three leaded brass objects (3.7 %) were documented: a finger ring (DJ00101) and a ring (DJ00121) with 12.1 % – 14.1 % Zn and 3.12 % – 3.73 % Pb, and a bracelet (DJ00115) with low levels of both Zn (2.85 %) and Pb (2.72 %) (Table 4). In the leaded bronzes we can observe two pieces (DJ00161 (6) and DJ00107) with similar Sn and Pb levels (2.07 % – 2.77 % Sn and 2.39 % – 2.69 % Pb), two finger rings (DJ00109 and DJ00133) and an indeterminate metal fragment (DJ00154) with higher values of Sn (7.40 % – 11.1 %) than Pb (2.67 % – 4.95 %) and five objects –2 buckles (DJ00102 and DJ00111), a finger ring (DJ00099), a bracelet (DJ00122) and an earring (DJ00100)– with higher amounts of Pb (5.61 % – 14.1 %) than Sn (3.49 % – 6.27 %). Leaded gunmetal, however, does tend to have higher percentages of Zn (2.99 % – 13.4 %) and Sn (2.08 % – 12.7 %) than Pb (2.10 % – 8.92 %). Only in the lyriform belt buckle (DJ00160) do the Pb levels (8.92 %) exceed those of Zn (2.99 %) and Sn (6.48 %) and only in three cases are those of Pb lower than those of Zn but higher than those of Sn: two earrings (DJ00127 and DJ00128) with 8.83 % and 10.3 % Zn, 2.78 % and 2.37 % Pb, and 2.08 % and 2.19 % Sn respectively, and one hoop earring plate (DJ00117 (2) with 13.4 % Zn, 6.53 % Pb and 4.41 % Sn (Fig. 6).

5.2. Lead isotope results

For lead isotope analyses, six brass samples (Supplementary Material) with high Zn contents (15 % - 20 % Zn) and low Pb contents (<0.8 % Pb) were selected in order to avoid the isotopic distortion that could result from the mixing and recycle of metals, assuming that brasses with such a high Zn content and low levels of other impurities (<1%) are primary productions. Only one leaded gunmetal (DJ00160) was included for the analysis, as it was a lyriform buckle and because the existence of workshops in the *Hispalis* region for this specific type of piece has been proposed (Ripoll, 1998, 1999). In this case, the high Pb content (8.92 %) determines that the priority isotopic contribution would have resulted from the origin of the lead rather than that of copper.

In general, the samples do not show a large isotopic dispersion, with values ranging between 18.296 and 18.601 in the ^{206}Pb/^{204}Pb ratio, and 15.637 and 15.677 in the ^{207}Pb/^{204}Pb ratio (Table 5), highlighting the earrings DJ00119 and DJ00120 from the same grave, which have an almost identical isotopic signature (Fig. 7). The buckle DJ00160 do not differ from the other objects, therefore suggesting that the copper and lead came from deposits with similar lead isotope signatures.

6. Discussion

In his works on Late Antique archaeometallurgy, Rovira Llorens et al., 1989; Rovira Lorens, 2017; Rovira Llorens, 1987) alluded to the interest that statistical studies of certain impurities could have. Pernicka (1999) also discussed the importance of trace elements in the analysis of ancient copper and listed the elements according to their potential uses in archaeometallurgy. For its part, the Oxford team established 16 copper categories in a classification system based on the presence (>0.1 %) or absence (<0.1 %) of the four most common key copper trace elements: arsenic (As), antimony (Sb), silver (Ag) and nickel (Ni), since these are related to the mineral source and cover a range of thermodynamic behaviours in molten copper –under oxidising conditions, arsenic is volatile, antimony slightly less volatile, and silver and nickel stable– (Bray et al., 2015; Pollard et al., 2015; Pollard, 2018: 85). Assuming that

Table 3
Results of X-ray fluorescence analysis (pXRF) sorted by alloy type (values in %).

Alloy	ID	Material	Fe	Ni	Cu	Zn	As	Ag	Sn	Sb	Pb
Brass	301	Earring	0.13	<LOD*	74.8	23.6	<LOD	<LOD	0.06	<LOD	0.91
	DJ00108	Finger ring	0.17	0.15	78.1	20.9	<LOD	<LOD	0.11	<LOD	0.41
	DJ00169	“Basket”	0.15	0.15	77.3	20.7	<LOD	<LOD	1.45	0.15	<LOD
	Sep. 45	Ring setting	0.20	0.20	76.4	20.3	<LOD	<LOD	1.05	0.39	<LOD
	DJ00120 (2)	Hoop earring plate	0.14	0.09	78.5	20.3	<LOD	<LOD	0.45	<LOD	0.30
	DJ00119	Earring	0.03	0.07	80.2	19.0	0.09	<LOD	0.17	0.04	0.36
	DJ00233	Finger ring	0.14	0.13	78.9	18.7	0.05	<LOD	1.81	<LOD	0.11
	DJ00103	Earring	0.60	0.16	77.8	18.3	<LOD	<LOD	1.74	0.09	1.01
	DJ00136	Earring	0.10	0.09	81.9	17.3	0.09	<LOD	0.36	0.02	0.10
	DJ00118	Earring	0.17	0.10	80.7	17.1	<LOD	<LOD	0.87	0.05	0.87
	40,014	Finger ring	0.13	0.12	81.2	16.3	<LOD	<LOD	1.62	<LOD	0.54
	DJ00164	Belt plate	0.10	0.04	83.2	16.1	0.08	<LOD	<LOD	<LOD	0.04
	DJ00117	Earring	0.15	0.18	81.7	15.8	<LOD	<LOD	0.95	<LOD	0.89
	DJ00120	Earring	<LOD	0.07	82.4	15.4	<LOD	<LOD	0.20	0.05	0.29
	DJ00138	Finger ring	0.18	0.12	82.2	15.4	<LOD	<LOD	0.97	<LOD	1.04
	DJ00153	Finger ring	0.27	0.17	83.5	15.4	<LOD	<LOD	0.48	<LOD	0.11
	10,006	Ring setting	0.17	0.21	82.2	15.0	<LOD	<LOD	0.81	0.42	<LOD
	20,004	Indeterminate metal fragment	0.19	<LOD	84.8	13.9	<LOD	<LOD	0.58	0.08	0.48
	DJ00161 (3)	Pin	0.09	0.08	85.2	13.9	0.08	<LOD	0.45	<LOD	0.10
	DJ00166	Small hoop	0.14	0.08	83.8	13.6	<LOD	<LOD	1.99	<LOD	0.29
	DJ00150	Earring setting	0.21	0.18	83.6	12.8	<LOD	<LOD	1.90	0.07	0.99
	DJ00150	“Basket”	0.14	0.14	87.1	10.2	<LOD	0.21	1.18	0.06	0.90
	DJ00105	Earring	0.15	0.07	87.7	8.75	<LOD	<LOD	1.93	0.05	1.14
Gunmetal	DJ00168	Small hoop	0.12	0.05	77.6	18.1	<LOD	<LOD	2.89	0.06	0.65
	DJ00134	Finger ring	0.31	0.06	79.8	16.8	<LOD	<LOD	2.55	0.23	0.24
	Sep. 33	Earring setting	0.21	0.12	76.9	15.9	<LOD	<LOD	2.68	0.25	0.30
	DJ00132	Finger ring	0.24	0.12	81.8	14.4	<LOD	<LOD	2.05	0.06	1.27
	DJ00149	Earring setting	0.16	0.20	83.8	11.0	<LOD	0.44	2.20	0.27	1.79
	DJ00152	Finger ring	0.10	<LOD	85.7	11.0	<LOD	<LOD	2.20	0.11	0.81
	DJ00129	Pin	0.41	0.11	79.6	10.2	<LOD	<LOD	2.75	<LOD	1.72
	DJ00142	Finger ring	0.31	0.13	83.9	10.0	<LOD	<LOD	3.79	0.09	1.66
	DJ00137	Finger ring	0.19	0.11	84.3	9.38	<LOD	<LOD	4.28	0.11	1.65
	DJ00161 (4)	Pin	0.06	0.29	85.9	9.18	0.43	<LOD	3.90	<LOD	0.17
	DJ00143	Finger ring	0.15	0.06	85.9	8.80	<LOD	<LOD	3.75	0.11	1.18
	DJ00140	Finger ring	0.11	<LOD	86.6	8.44	<LOD	<LOD	3.13	0.07	1.52
	DJ00114	Bracelet	0.73	<LOD	83.9	8.36	0.23	<LOD	5.92	0.20	0.23
	4402–4	Pin	0.20	0.07	86.3	7.51	<LOD	<LOD	4.44	<LOD	1.15
	DJ00113	Bracelet	0.27	<LOD	86.4	6.77	0.23	<LOD	5.56	0.21	0.21
Bronze	DJ00139	Finger ring	<LOD	<LOD	78.1	<LOD	<LOD	<LOD	21.2	0.16	0.40
	DJ00135	Finger ring	0.46	<LOD	79.8	<LOD	<LOD	<LOD	18.1	<LOD	<LOD
	DJ00110	Bracelet	0.13	0.08	87.4	<LOD	<LOD	<LOD	11.7	<LOD	0.15
	DJ00131	Finger ring	0.12	<LOD	88.3	<LOD	0.28	<LOD	11.0	<LOD	0.13
	40,014 (1)	Ring setting	0.07	<LOD	89.3	<LOD	0.04	<LOD	10.3	0.08	0.03
	DJ00112	Earring	0.32	<LOD	89.0	<LOD	0.08	<LOD	9.89	0.12	0.36
	DJ00141	Finger ring	0.07	<LOD	90.5	<LOD	0.04	<LOD	9.11	0.06	0.08
	DJ00130	Finger ring	0.28	<LOD	91.6	<LOD	<LOD	<LOD	7.61	0.11	0.32
	DJ00161 (2)	Pin	0.94	<LOD	90.8	<LOD	<LOD	<LOD	6.98	<LOD	0.30
	4402–2	Pin	0.09	0.03	95.1	0.19	<LOD	<LOD	3.29	0.09	1.13
	DJ00124	Pin	0.15	<LOD	93.2	1.49	<LOD	0.23	2.83	0.12	1.92
	4402–1	Pin	0.26	<LOD	88.9	<LOD	<LOD	<LOD	2.63	0.11	1.19
	DJ00161 (1)	Pin	0.16	<LOD	95.5	0.16	<LOD	<LOD	2.29	0.16	1.02
Leaded bronze	DJ00109	Finger ring	0.31	<LOD	83.1	0.37	<LOD	<LOD	11.1	0.10	4.95
	DJ00154	Indeterminate metal fragment	0.15	<LOD	84.6	<LOD	<LOD	0.33	7.83	<LOD	3.23
	DJ00133	Finger ring	0.54	<LOD	87.4	0.65	0.35	<LOD	7.40	0.76	2.67
	DJ00102	Buckle	<LOD	<LOD	79.5	<LOD	<LOD	<LOD	6.27	0.06	14.1
	DJ00099	Finger ring	0.05	0.23	85.1	<LOD	<LOD	<LOD	6.14	0.33	8.01
	DJ00122	Bracelet	0.19	<LOD	84.8	0.39	<LOD	<LOD	5.55	0.10	8.44
	DJ00100	Earring	0.33	<LOD	86.6	0.73	1.40	<LOD	5.27	0.20	5.36
	DJ00111	Buckle	0.09	<LOD	88.5	1.30	<LOD	<LOD	3.49	0.06	5.61
	DJ00161 (6)	Pin	0.12	<LOD	92.7	1.69	<LOD	<LOD	2.77	0.13	2.39
	DJ00107	Finger ring	0.51	0.18	94.0	0.39	<LOD	<LOD	2.07	0.07	2.69
Leaded gunmetal	DJ00117 (2)	Hoop earring plate	0.13	0.11	75.3	13.4	<LOD	<LOD	4.41	<LOD	6.53
	DJ00167	Small hoop	0.19	0.14	78.3	13.3	<LOD	<LOD	4.56	0.07	3.29
	DJ00127	Earring	0.15	<LOD	84.9	10.3	<LOD	<LOD	2.08	0.06	2.37
	DJ00144	Ring setting	1.97	0.76	63.3	10.2	<LOD	1.19	12.7	2.65	4.22
	DJ00149	“Basket”	0.20	0.14	78.5	9.36	<LOD	0.63	6.49	0.28	4.40
	DJ00128	Earring	0.19	<LOD	85.8	8.83	<LOD	<LOD	2.19	0.05	2.78
	DJ00106	Earring	0.15	0.09	81.1	7.56	0.18	<LOD	8.47	0.04	2.10
	DJ00104	Earring	0.17	0.06	76.2	6.19	0.38	<LOD	11.4	0.05	5.04
	DJ00161 (5)	Pin	0.16	0.07	86.8	6.09	<LOD	<LOD	4.30	0.07	2.43
	DJ00160	Buckle	0.17	0.05	81.2	2.99	<LOD	<LOD	6.48	0.10	8.92
Copper	4402–3	Pin	<LOD	<LOD	99.6	<LOD	0.19	<LOD	<LOD	<LOD	<LOD
	DJ00126	Pin	0.19	0.20	97.8	<LOD	<LOD	<LOD	0.73	<LOD	0.41
	4402–6	Pin	0.19	0.21	97.5	<LOD	0.33	<LOD	<LOD	<LOD	0.13

(*continued on next page*)

Table 3 (*continued*)

Alloy	ID	Material	Fe	Ni	Cu	Zn	As	Ag	Sn	Sb	Pb
	4402–5	Pin	0.12	<LOD	97.4	<LOD	<LOD	<LOD	1.26	0.09	0.87
	4402	Pin setting	0.26	<LOD	97.3	<LOD	<LOD	<LOD	0.82	0.05	1.38
	DJ00170	Pin	0.17	<LOD	97.3	<LOD	<LOD	<LOD	1.68	0.04	0.75
Leaded brass	DJ00121	Ring	1.15	<LOD	79.5	14.1	<LOD	<LOD	1.28	0.06	3.12
	DJ00101	Finger ring	0.19	0.13	80.7	12.1	<LOD	<LOD	1.72	0.04	3.73
	DJ00115	Bracelet	0.16	<LOD	92.5	2.85	<LOD	<LOD	1.64	0.05	2.72

*LOD: Limit of detection

Table 4
Types of alloys present in the analysed artefacts from Cortijo del Chopo (Granada).

	Copper	Bronze	Leaded Bronze	Brass	Leaded Brass	Gunmetal	Leaded Gunmetal	No. Objects
Finger rings		5	4	5	1	7		22
Pins and a pin setting	6	5	1	1		3	1	17
Earrings		1	1	8			4	14
Earring settings and “baskets”				3		2	1	6
Bracelets		1	1		1	2		5
Belt components			2	1			1	4
Finger ring settings		1		2			1	4
Small hoops				1		1	1	3
Others			1	1	1			3
Hoop earring plates				1			1	2
No. analyses	6	13	10	23	3	15	10	80
Total percentage	**7.5 %**	**16.2 %**	**12.5 %**	**28.7 %**	**3.7 %**	**18.7 %**	**12.5 %**	**100 %**

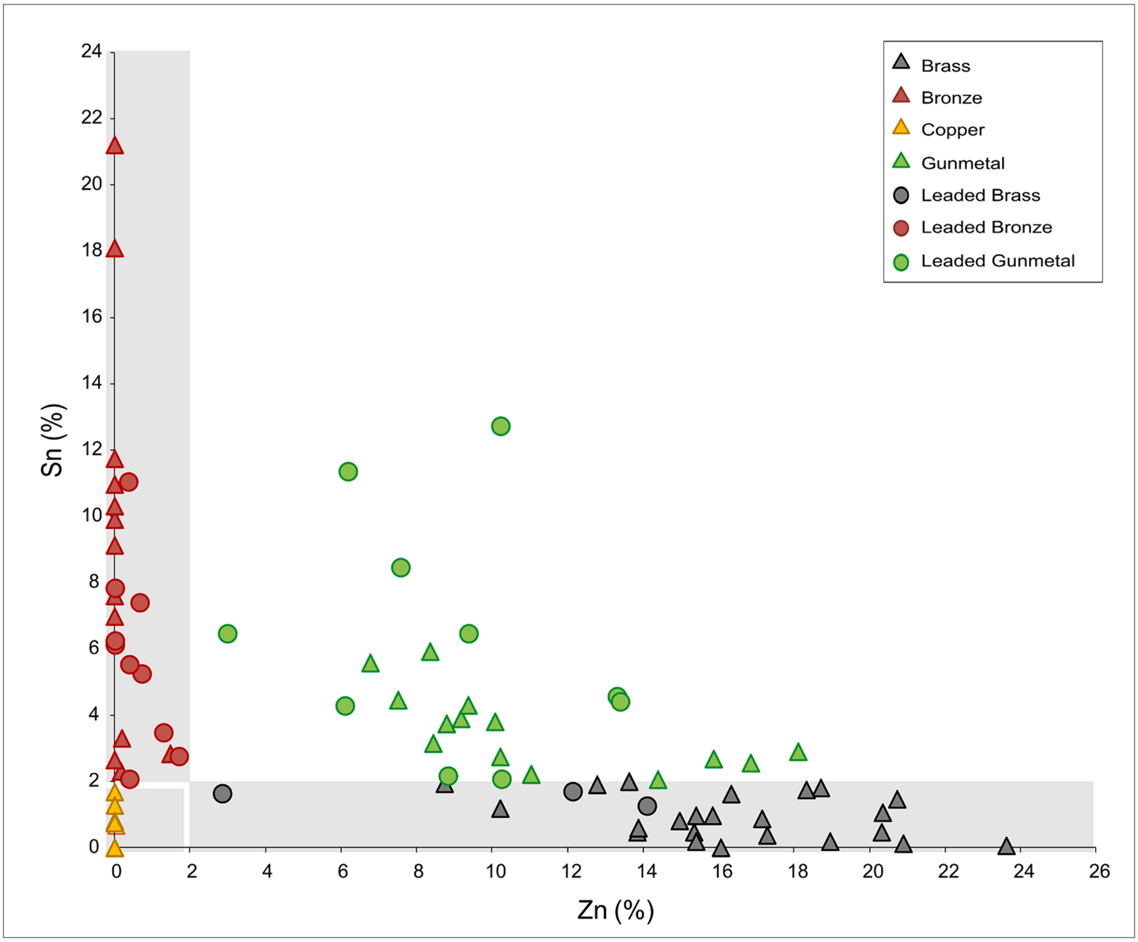

Fig. 5. Graph of the analysed objects according to their Sn/Zn content.

most of the impurities would have come from the copper, these categories allow us to compare the copper base used in the different alloys. In 40 % of the analysed finds from Cortijo del Chopo necropolis none of those elements was detected (CC1) (Table 6), and the number of earrings (8) and pins (7) that are part of this category is remarkable. Regarding the presence of impurities, of particular note is the 20 % of adornments

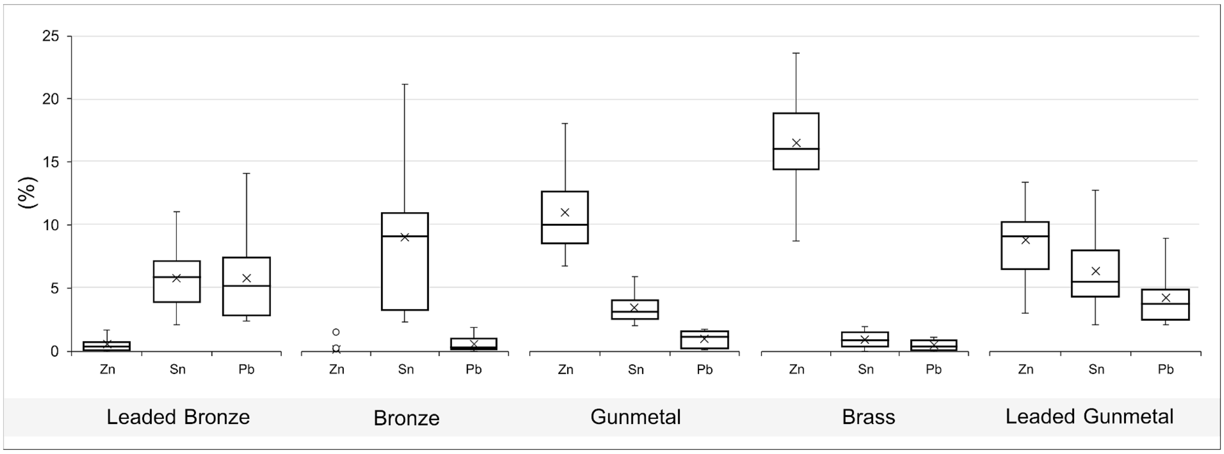

Fig. 6. Box and whisker plot showing the percentage of Zn, Sn and Pb of the alloys with the highest ubiquity in the assemblage analysed.

Table 5
Pb isotope analysis data and alloy type of the samples measured in this study.

ID	Sample	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{204}Pb$	$^{208}Pb/^{204}Pb$	$^{208}Pb/^{206}Pb$	$^{207}Pb/^{206}Pb$	Alloy	%Pb
DJ00117	Earring	18.354	15.664	38.551	2.10044	0.85346	Brass 15.8 % Zn	0.89
DJ00118	Earring	18.502	15.673	38.697	2.09149	0.84711	Brass 17.1 % Zn	0.87
DJ00119	Earring	18.591	15.676	38.734	2.08351	0.84320	Brass 19 % Zn	0.36
DJ00120	Earring	18.601	15.677	38.745	2.08292	0.84280	Brass 15.4 % Zn	0.29
DJ00108	Finger ring	18.349	15.645	38.500	2.09828	0.85266	Brass 20.9 % Zn	0.40
DJ00164	Belt plate	18.296	15.637	38.476	2.10298	0.85466	Brass 16.1 % Zn	0.04
DJ00160	Lyriform belt buckle	18.534	15.668	38.677	2.08675	0.84535	Leaded Gunmetal	6.53

that contain more than 0.1 % Ni (CC5), most of them are finger rings, followed by 12.5 % that contain Sb (CC3), and 7.5 % in which traces of both components are documented (CC10). The objects that can be assigned to this last category are represented mostly by settings.

The copper categories recorded in the necropolis reveal similarities with the reference copper categories we currently have for the Late Antiquity finds assemblage (Table 6). These were defined from a total of 390 objects analysed as part of the Iberian Peninsula Archaeometallurgy Project (Montero Ruiz and Orejas, 2018). In Hispanic metals, as at Cortijo del Chopo, a fairly pure copper (CC1) or with nickel (CC5) predominates from the early Roman period to Late Antiquity (Montero Ruiz and Orejas, 2018). However, there are notable differences in the percentages of some of them, such as the CC3 (higher Sb in Cortijo del Chopo) or CC11 (higher As and Ni in Iberian Peninsula) copper.

Regarding the alloys documented in this study, the differential pattern in brass and bronze objects stands out. While the main impurity in brass is Ni, it is almost completely absent from bronzes and leaded bronzes, with Sb being that predominant in the latter cases (Fig. 8). Likewise, Sb and Ni remain the main impurities in gunmetal and leaded gunmetal. This differential model could indicate the use of two different supply sources for the production of brass and bronze. However, it is also worth noting the different pattern of impurities between the two groups of bronzes. While the bronzes poor in Sn (<3.3 % Sn) have higher values of Pb (1.3 % on average), Sb (0.1 % on average) and Zn (0.5 % on average), the bronzes richer in Sn (>7% Sn) are purer, with lower values of Pb (0.2 % on average) and Sb (0.06 % on average). Zn is not detected in this group and there are low levels of As (0.05 % on average), which was not documented in the poor bronzes. Ni, with a greater presence in brasses, is a residual element in both groups of bronzes, only 0.03 % is found in a poor bronze and 0.08 % in a rich bronze. This differential pattern of impurities in the >7 % Sn and Sn-poor (<3.3 % Sn) bronzes and the fact that all the Sn-poor bronzes are pins seems to indicate greater recycling of the metal for the manufacture of those items.

6.1. The relationship between adornments and their composition

The assemblage of copper-based alloy elements analysed would have been formed during the necropolis' long period of use. The multiplicity of ornamental pieces made from such diverse alloys is probably due to the fact that they were manufactured at different times, in various production centres and with varying metal resources. Since the vast majority are of Roman tradition, it is difficult to establish differences based on their chronology that would facilitate the identification of patterns and production workshops or the evolution of the metallurgical activity in the area.

The detailed study of the different types of objects from Cortijo del Chopo has allowed us to observe that, in broad terms, some of them present a link with their chemical composition (Fig. 9). In the first place, there seems to be a tendency for the pins (Fig. 4o) to be made of copper. When this type of item has been made from another alloy, it has a lower proportion of the alloying element than the rest of the pieces. Previous research on Roman artefacts from Lusitania province has indicated that copper was also preferred for simple artefacts, such as nails and rivets (Valério et al., 2015, 2023).

The finger rings (Fig. 3a-d) were made from a wide variety of alloys, although the closed and adjustable forms contain a higher percentage of Sn than those with a setting, whose Zn content is higher. Earrings (Fig. 3f-g) generally contain Zn levels that range between 6 % and 23 %, with an average of 12 %, making them the finds with the highest average amounts of that element. We only found two exceptions in which the Zn

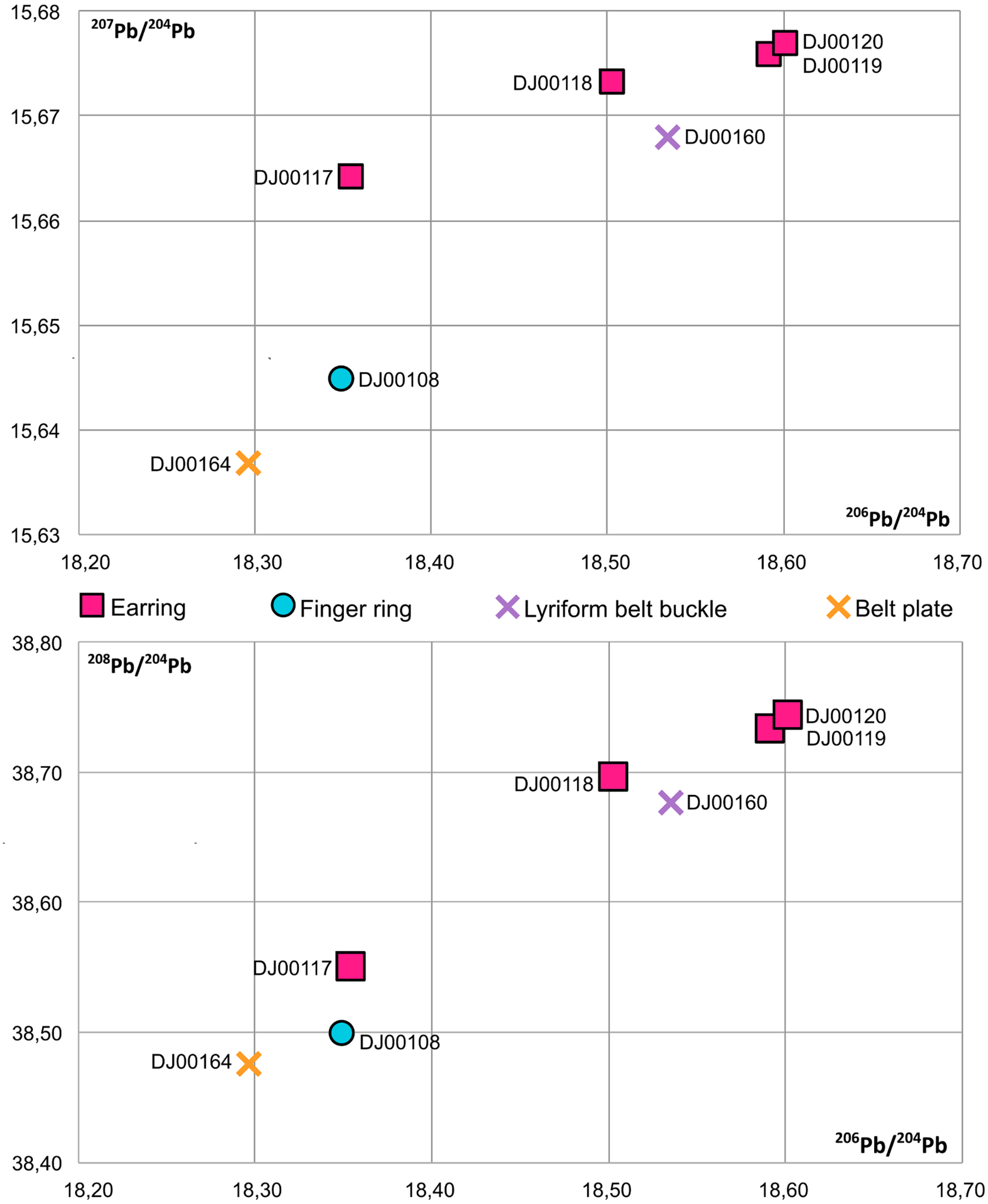

Fig. 7. Pb isotope diagram of the analysed dress accessories.

value was less than 1 %. In one of them the non-pointed end has parallel incisions, while the other is rectangular in section with a simple hook closure (Fig. 3e). Of these pieces, it is also worth noting the similarity in the chemical composition of the pairs of earrings, as well as the pair of bracelets, which could indicate that they were made in a single casting.

The settings and small hoops (Fig. 3h) that are part of the earrings have a high Zn content (9 – 20 %) in common, as do the ring settings, with the sole exception of one specimen cast in bronze. However, they were all made from a wide variety of alloys, which seems to indicate little concern for the selection of the metal with which they were manufactured and that all kinds of metal could have been used.

Regarding the elements that would have been part of belts, we would like to highlight the difference between the composition of the lyriform belt buckle (Fig. 4k) and the kidney-shaped (Fig. 4l) and rectangular buckles (Fig. 4m). These were made of leaded gunmetal alloys and leaded bronze respectively and stand out for their high lead content (5.61 % – 14.1 %), compared to the decorated rectangular belt applique (Fig. 4n), which is a brass metal without impurities (16.1 % Zn). For the production of the buckles, the addition of Pb to the casting may have been for technological questions, as it would have facilitated the moulding of the object (Rovira Llorens, 2017), while the decorative plate is a thin sheet whose purpose and manufacture are very different.

Table 6

Proportion of impurities present in the metal (>0.1 %) from Cortijo del Chopo necropolis, based on the copper categories established by Pollard et al. (2015), and their comparison with the categories defined (>0.15 %) for the Late Antiquity by Montero Ruiz and Orejas (2018).

	Copper	Bronze	Leaded bronze	Brass	Leaded Brass	Gunmetal	Leaded Gunmetal	Cortijo del Chopo	Iberian Peninsula
CC1	3	6	4	11	2	3	3	40 %	24.9 %
CC2 (As)	1	1					2	5 %	5.1 %
CC3 (Sb)		5	1			3	1	12.5 %	4.6 %
CC4 (Ag)			1					1.25 %	3.3 %
CC5 (Ni)	1		1	8	1	3	2	20 %	32.6 %
CC6 (As, Sb)			2			2		5 %	1.3 %
CC7 (Sb, Ag)		1						1.25 %	2.8 %
CC8 (Ag, Ni)				1				1.25 %	3.6 %
CC9 (As, Ag)								0 %	0.3 %
CC10 (Sb, Ni)			1	3		2		7.5 %	6.4 %
CC11 (As, Ni)	1					1		2.5 %	9.5 %
CC12 (As, Sb, Ag)								0 %	0.5 %
CC13 (Sb, Ag, Ni)						1	2	3.75 %	1.5 %
CC14 (As, Sb, Ni)								0 %	3.1 %
CC15 (As, Ag, Ni)								0 %	0.3 %
CC16 (As, Sb, Ag, Ni)								0 %	0.3 %

6.2. *The use of surplus and recycled metal for the manufacture of personal ornaments*

According to Bray et al. (2015), if a high proportion of an assemblage is composed of a leaded gunmetal type alloy, this suggests that the objects may be the result of mixing metals from more than one type of alloy, rather than a deliberate alloy design. It is, therefore, a clear indication of the increasingly widespread practice of mixing and recycling metal in general (Pollard et al., 2015), which is closely linked to the mutability of copper and its relative resistance to corrosion, which makes it lend itself to long and complex lives (Bray et al., 2015).

Minor elements that can be detected in the metal, such as arsenic, antimony, nickel and silver, can be used to assess the recycling and even the contribution of new metal. Their presence depends on the type of mineral exploited and metallurgical processes applied and, therefore, the changes in the impurity models reveal variations in the metal supply, including the practice of recycling (Pollard et al., 2015; Montero Ruiz and Orejas, 2018). On the Iberian Peninsula, there are few notable differences in the proportion of impurities in the Late Antique finds with respect to the early Roman period. In the specific case of the analysed necropolis, they even appear to show the perpetuation of metallurgical practices.

In Cortijo del Chopo, there is a 12.5 % of leaded gunmetal and a 18.7 % of gunmetal, a slightly higher figure than that defined based on the rest of the analysed objects from the Iberian Peninsula (29.3 % leaded gunmetal and 4.1 % gunmetal) (Montero Ruiz and Orejas, 2018), such as brooches and buckles of very varied typologies. The pieces made from a gunmetal-type ternary alloy have a Zn content of as much as 18.1 % and Sn of less than 5.92 %, which makes the assemblage a complex group (50 % of the objects correspond to finger rings). Small ornaments also make up 50 % of the leaded gunmetal assemblage and, in this case, present more varied percentages of Zn, Sn and Pb, although the high Zn content (8.8 % on average) continues to stand out.

The high average zinc content of the gunmetals and leaded gunmetals also differs from the funerary context finds from the centre of the Iberian Peninsula, such as those from Castiltierra (Rovira Llorens, 2017). It is therefore possible that the recycling at Cortijo del Chopo was concentrated in the copper base used to make brass. The greater or lesser recycle of the copper base would have resulted in brasses with a greater or lesser degree of impurities.

The pieces analysed by lead isotope, mostly brass, present considerable homogeneity in their isotopic ratios. They also correlate well with the ore deposits in the surrounding area, as will be seen later. This excludes, for these pieces at least, recycling and the use of resources from disparate provenances, as has been pointed out for the Roman production of brasses in the Alpine region (Bursák et al., 2022).

Regarding the archaeological evidence of the activity, in the Iberian Peninsula and, as an example, in the Morería Archaeological Area (Mérida) (Fig. 1), corresponding to the late-period neighbourhood that reoccupied the Roman-era residential spaces, diverse metal objects were documented in relation to various metal smelting workshops. Their presence could indicate that they were destined to be recast to make or repair other pieces (Alba Calzado, 1997). Along the same lines, Palol (1953) inferred that the objects of varied origin and chronology (4th-7th centuries AD) found in the Collet de Sant Antoni de Calonge (Girona) deposit were working materials from a workshop involved in casting or repairing bronzes, which had its own reserves of pure unworked copper along with scales to check the weights. As for the south of the Peninsula, no deposits of these characteristics have been identified in clear contexts (nor indeed metal production areas or structures). However, the study of

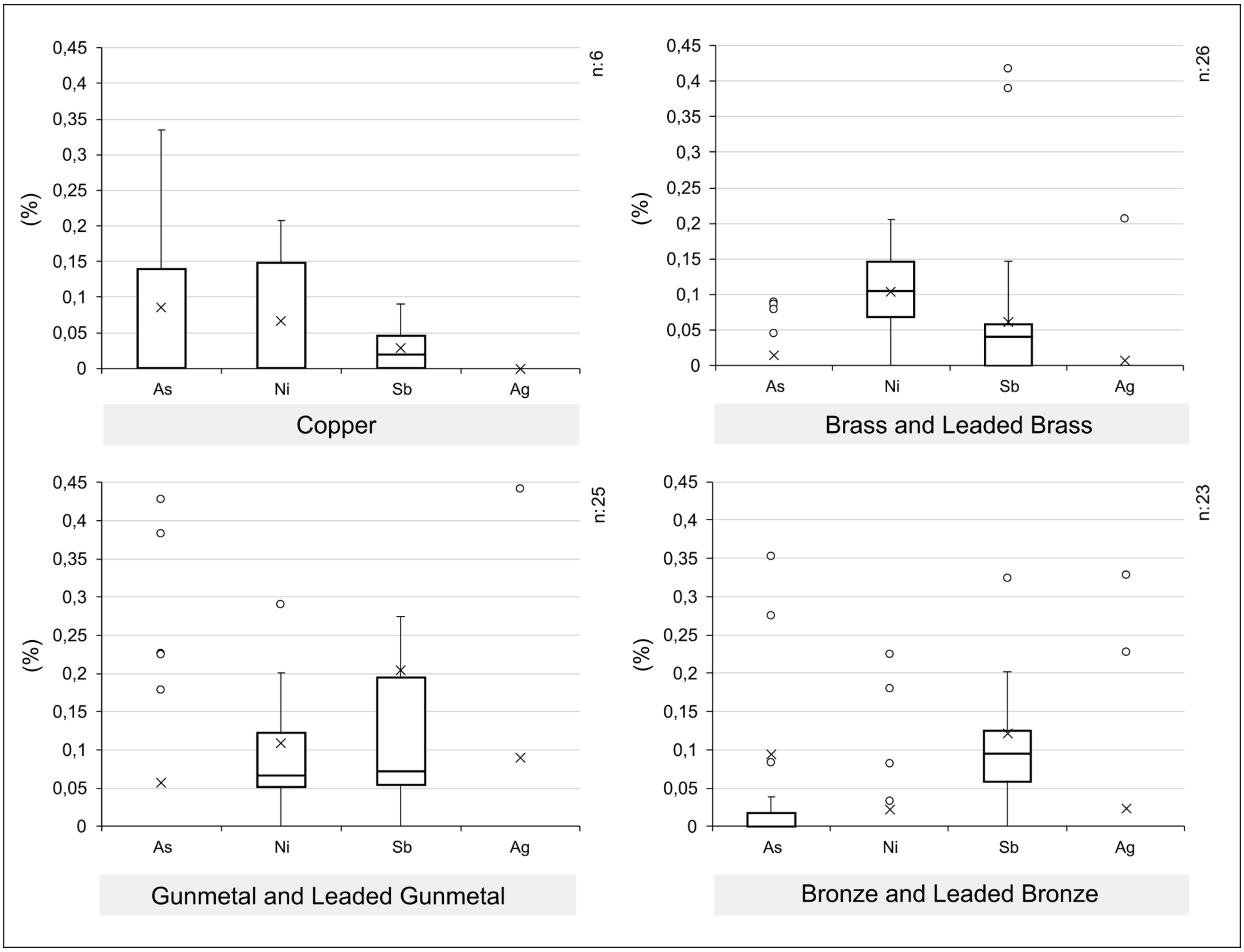

Fig. 8. Box and Whiskers diagrams showing the percentage of the trace elements: As, Ni, Sb and Ag of the analysed sample. High As and Sb values (1.40 % and 0.76 % respectively) of two leaded bronze objects are left out of the graph. As well as the Ni and Sb levels (0.76 % and 2.65 % respectively) of a leaded gunmetal ring setting, and the Ag values of another setting and an earring basket (0.63 % and 1.19 % Ag).

the lyriform belt buckles from the area around *Hispalis* (Seville) has revealed the existence of a small number of *officinae* in the area, at least throughout the 7th century CE, and it has been suggested that these used recycled materials (Ripoll, 1998,1999). Otherwise, of earlier chronology, the Roman site of Monte Molião (south Portugal) showed "a space dedicated to metallurgical operations, which produced artifacts in bronze and iron. This function was established by the presence, in a compartment of 18 m^2, of remains of baked clay, concentrations of ashes, dripping remains and slags of the metal work and even artifacts, some intact, others fractured" (Arruda and Pereira, 2010).

In the Hispanic area, in general, there are few deposits of materials that could have been collected or used for reworking. Therefore, the scope and nature of this recycling practice, together with the conservation of objects for long periods within families, must be assessed locally, since they could also manifest in very different ways in urban centres and rural areas (Giannichedda, 2008).

Depending on its metal availability and political, economic and social organisation, each territory will have a history of different metallurgical practices, and the use and recycling of metal will therefore correspond to their specific circumstances. For example, the scarcity of resources in Britain meant that a "convenience metallurgy" was practised (Baker, 2013), while in Late Antiquity Hispania, with a much lower ubiquitousness of ternary and quaternary alloys (Montero Ruiz and Orejas, 2018), it is necessary to delve into the reasons that led to this practice, and to ascertain whether there was any relationship between certain geographical areas and specific types of object. Not all regions of the Iberian Peninsula would have had the same access to mineral resources (even when the South is rich in copper and zinc ore sources). Furthermore, not in all cases would surplus or out-of-circulation metals have been used, or even had access to them, since we do not know whether the recycled piece(s) had any ancestral value (Caple, 2010).

6.3. High zinc content artefacts and brass production

By the mid-1st century BCE, at the latest, the Romans had begun to produce brass on a large scale, and during the 1st and 2nd centuries AD its use spread rapidly. However, despite what we can deduce from the bronzes themselves and from Pliny and Dioscorides' references, little is known about Roman brass production techniques (Craddock, 1978). Even Isidore of Seville (6th –7th century AD), in the chapter dedicated to copper in the *Etymologies* (XVI, 20, 3), makes hardly any reference to *aurichalcum* (Díaz y Díaz, 1970).

Also, very few cases of brass-making installations have been published, and the limited examples of crucibles used in the process have very varied characteristics (Rehren and Martinón-Torres, 2008). For brass alloying, smithsonite ($ZnCO_3$), known as calamine, or sphalerite (ZnS) was used, and the method –copper reaction with zinc vapour– required temperatures of around 900–1100 °C and a reducing environment to avoid the loss of zinc through evaporation, a procedure that limits the absorption of zinc to values of around 30 %. This is also

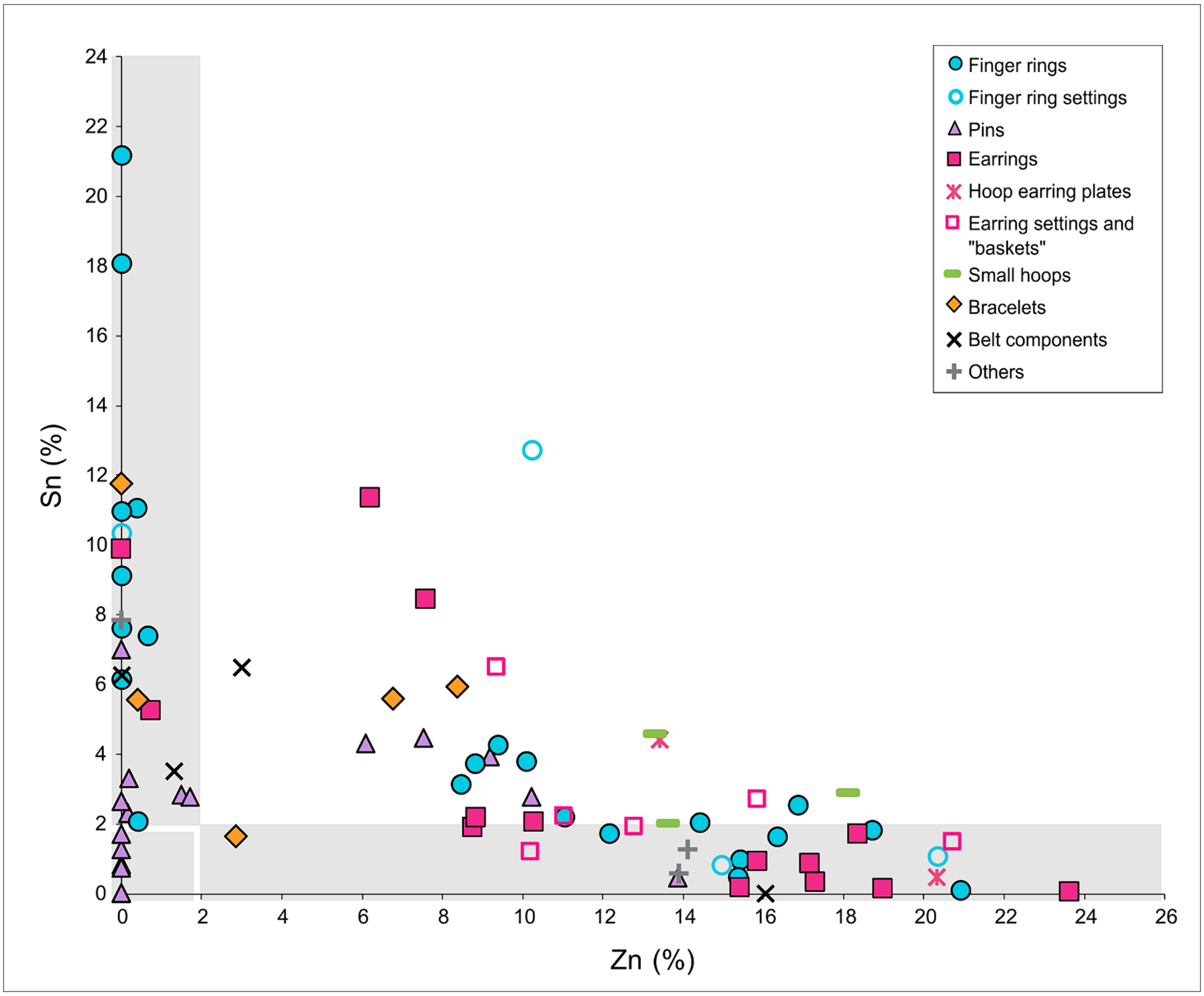

Fig. 9. Relationship of the types of objects analysed and the Sn/Zn ratio of their composition.

influenced by the type of copper variant used, since some are more suitable for manufacturing brass than others; as can be seen in the freshly made brasses from the assemblage analysed in this paper. The nuances of the manufacturing process have been the subject of in-depth reflection by a number of researchers (e.g. Haedecke, 1973; Rehren, 1999; Craddock and Eckstein, 2003; Rehren and Martinón-Torres, 2008; Marqués Sierra, 2018).

In the analysed group of finds from Cortijo del Chopo necropolis, the brass elements (28.7 %) have Zn values of between 8.75 % and 23.6 %, with an average of 16.5 %. This seems to indicate that the knowledge of metal working technology was transferred over time from the early Imperial period, when good quality brasses were already being made (Montero Ruiz and Orejas, 2018), as they probably followed the same parameters as Roman technology (Rovira Llorens et al., 1989). In addition to excellent mastery of the process, it appears that the artisans had good access to the mineral resources, allowing them to make ostentatious adornments that resembled gold in appearance.

The pieces made with a gunmetal-type alloy (18.7 %), as we have said, contain an average of ca. 11 % Zn and ca. 3.5 % Sn. This led us to consider that many of them could have been produced with the intention of obtaining brass based on recycled bronzes. As the presence of certain levels of Sn in the copper base metal may have limited Zn absorption (Craddock, 1978). Therefore, we propose that the presence of this in the alloy would have been somewhat fortuitous, since the intentional aggregation of Sn would not have improved the mechanical conditions of the metal nor would it have altered its physical features. Moreover, on the Iberian Peninsula, the ubiquity of bronze and gunmetal (4.1 % in both cases) decreased considerably in Late Antiquity (Rovira Llorens et al., 1989; Montero Ruiz and Orejas, 2018), probably due to the lack of supply of Sn, the mines of which were concentrated in the northwest (Puche Riart and Bosch Aparicio, 1995). We do not know how the metallurgists perceived their product and what type of "composition" they were looking for, nor indeed how they achieved it and for what purpose. However, if we take into account the social context in which the pieces belonging to the analysed assemblage were manufactured, the senses surely held a prominent place within the skills associated with metalworkers (Kuijpers, 2013). Therefore, aspects such as the appearance of the metals must have played an important role in the manufacturing process, which could be the reason for the numerous Sn-poor brasses to which we refer above.

6.4. Metal provenance

The lead isotope results appear to indicate that both the brass objects and the leaded gunmetal lyriform buckle DJ00160 (Supplementary Material) analysed may be associated with the ore deposits from the Interior Baetic Cordillera (Murillo-Barroso et al., in press), more specifically the eastern area of Granada near Almería, which, together with the high Zn levels documented in the Cortijo del Chopo necropolis, appears to be indicative of local brass production.

The Pb isotope characterisation of brasses is not free of problems, since the natural association of zinc and lead resources facilitates the contribution of Pb to the metallurgical product, which could obscure the isotopic fingerprint of copper. A recent study of Roman brasses and calamines from the Italian Alps indicates that the greater presence of lead in brasses compared to contemporary coppers and bronzes shows that the Pb contributions would have come mainly from Zn minerals. This in turn appears to be confirmed by Pb isotope studies that allow the brasses to be linked with Zn mineralisations (Merkel, 2021).

Although we do not have direct evidence of a metallurgical workshop, as thermal processing of zinc ores produces very little slag and thus provides little tangible surface evidence (Craddock and Eckstein, 2003), the results obtained lead us to propose that one or several workshops could have been located in or around Granada and that they would have at least produced brass. Indeed, there are several known from Late Antique period in the area of Guadix (centre-north of the province) intended for iron metallurgy (Bertrand et al., 1999).

In the area of the Sierra Morena and Baetican mountain there are zinc deposits of great importance (Fig. 1), such as those of Linares and Cartagena (I.G.M.E, 1972). In Granada province, zinc mines and traces of them have been identified in the Sierra de Baza mountains in the east; in Huetor Santillán, Quéntar, Güejar Sierra and Monachil, all located in the eastern part of the Vega de Granada, relatively close to the town of *Eliberri* (Granada) and the settlement and necropolis of Cortijo del

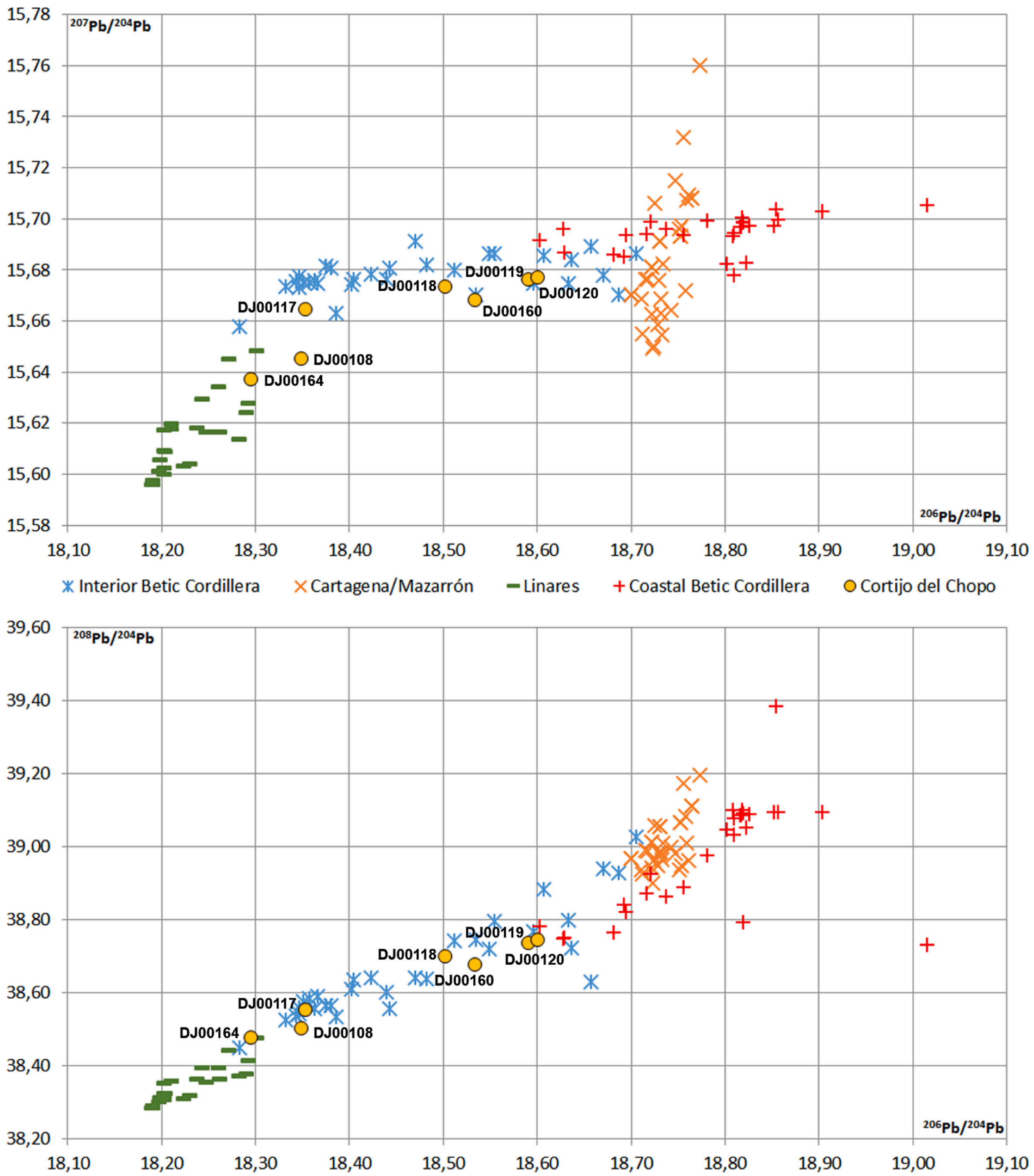

Fig. 10. Distribution of the pieces from Cortijo del Chopo necropolis (this paper) in comparison with the ore samples from the Linares mining district (data from Santos Zaldegui et al., 2004), Cartagena/Mazarrón (Graeser and Friedrich, 1970; Arribas and Tosdal, 1994; Stos Gale et al., 1995; Baron et al., 2017), the Coastal Betic Cordillera (Murillo-Barroso et al., 2019) and the Interior Betic Cordillera (data from Murillo-Barroso et al., in press). Note their association with the resources of the Interior Betic Cordillera and Linares.

Chopo. It is precisely with these mineralisations from the interior of the Baetican Mountains that the samples from Cortijo del Chopo are best associated, with the exception of the belt applique DJ00164, which is best linked to the Linares mineralisations (Fig. 10). Zinc deposits have also been documented in the Sierra de la Contraviesa, Sierra de Lújar and Sierra del Jaral mountains in the south (Ministerio de Industria and Dirección General de Minas, 1972; I.G.M.E, 1972: Fig. 2.1-9).

With regard to the analysed finds, based on the study of the lyriform belt buckles from the *Hispalis* area, Ripoll (1999) deduced the existence of workshops in the region. She also proposed the possibility of artisans working to order for customers in different zones, given the great similarity of these objects in the geographical area of the kingdom of Toledo and the *Narbonense*. The analysis of the buckle (DJ00160) revealed that the workshops making this type of piece were more widespread in the south of Iberia. The decorative brass belt plate (DJ00164) with a high Zn content (16.1 %), probably made with minerals from Linares (Jaén) (Fig. 10), has fewer parallels; they appear to be concentrated in the Málaga, Granada and Almería areas and have similar decorative patterns (Salinero Sánchez, 2021), which also seem to correspond to a local production from the southeast of the Iberian Peninsula.

The possibility that the dress fasteners and accessories were made locally raises many questions, such as the number of workshops, the size of the production, the clientele they supplied, the infrastructure, and how long they were made for.

6.5. *The colour and appearance of metals*

A wide variety of copper-based alloys was used to make the items of personal adornment found in Cortijo del Chopo necropolis. Therefore, the colour and appearance of the objects must have been decisive characteristics (Kuijpers, 2013; Mecking, 2020a, 2020b). This leads to the critical question as to what extent the alloys were manufactured and manipulated with the aim of producing specific colours or ranges of colour (Fang and McDonnell, 2011). The importance of the appearance of Late Antiquity metal artefacts is demonstrated by the considerable frequency with which the pairs of objects coincide and by the fact that many were given a surface treatment of gilding, tin-plating, niello-plating or damascening, among others.

It has been researched and discussed how alloying elements and heat treatments influenced the colour of copper-based alloys (Chase, 1994; Fang and McDonnell, 2011; Mecking, 2020a). In order to detect this influence in the analysed assemblage, we used the results obtained in the reference studies, as well as a system that makes it possible to deduce the colour of the copper alloys from the chemical composition of the objects (Mecking, 2020b). From its application, it is observed that in this set the brasses are particularly noteworthy (this is explained in more detail in the Supplementary Material), as they present similarities with 18 carat gold (Fig. 11). Specifically, among the necropolises documented in the province of Granada, the presence of gold ornaments is unusual, although the artisans who made the objects that accompanied those buried in the nearby cemetery of Marugán (Atarfe) had access to that precious metal (Peñalver y López, 1842). The most notable differences between gold and high-Zn brasses are related to their density and reaction to oxidation. To what extent the use of gold among members of those communities was the result of differences in status, is a question we cannot answer. In either case, the appearance that something is valuable is almost as important as owning it (Baker, 2013).

The objects analysed for this research constitute an assemblage with a certain homogeneity in terms of visual appearance, the most notable difference being the reddish colour of the pins, since most of the ornaments have a chemical composition that allows them to be placed in the gilded colour range. However, when we take into account the influence of the lack of precision in the expected appearance of the metals and the low sensitivity of the human ability to distinguish it, a wide variety of copper alloys could meet the visual expectations of gold. Only two rings (DJ00135 and DJ00139) with a high Sn content had a greyer, almost silvery colour. Therefore, it is possible to believe that the objects studied would have acted as precise chromatic reproductions of high-status alloys, since it is common for most members of a society to base their concepts of fashion and material value on those of the elites (Baker, 2013).

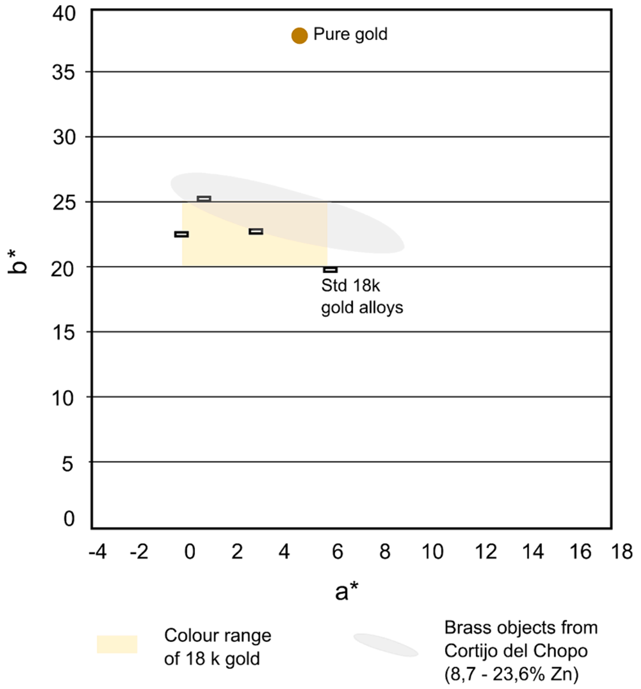

Fig. 11. Estimated indication of the location of the Cortijo del Chopo brasses in the CIELAB system, based on their chemical composition. Colour coordinates for 18 carat gold according to Levey et al., (1998: Fig. 9).

Also documented was a small group of iron bracelets and buckles on which no surface treatment can be observed, although they are very corroded. The colour of these objects contrasts with the rest of the ornaments made of copper-based alloys and the technology used to make them is also completely different. The significance of this minority presence is difficult to discern.

7. Conclusions

The results of the X-ray fluorescence (pXRF) and lead isotope analyses of the finds from Cortijo del Chopo, most of which are items of personal adornment, allow us to conclude that they are characteristic of Late Antiquity metalwork (Rovira Llorens et al., 1989; Rovira Llorens, 2017). In addition, of particular note is the wide variety of metal alloys registered.

The high percentage of Zn present in brasses of the analysed set, as well as in gunmetals, probably corresponds to a primary production of brasses. Lead isotope analyses revealed how several of the brass items were made from minerals consistent with the Interior Baetican Cordillera, near the necropolis, suggesting local production. The surrounding area has abundant Zn ore mines or indications of them, meaning there was easy access to that mineral. On the other hand, metallic materials that may be the product of recycling activity are also documented in the assemblage. Recycling usually has a negative connotation because it is associated with a scarcity of resources. However, it is necessary to evaluate the practice in each particular place or region, since it can also be a reflection of other procedures, such as recasting and reusing pieces that have been preserved for their significance to make new ones, or the use of surplus of metal. This latter case would seem to explain the varied composition of many of the finds analysed. The high presence of Zn in gunmetals and leaded gunmetals, as well the fact that artisans may have had access to copper and zinc mines, could show that they used all available metal resources to manufacture these pieces.

The status connotations of gold probably played an important role in the desire to develop metal alloys with a similar appearance. In the metallurgical craft of Antiquity, undoubtedly one of the main tools was the senses, and it is essential to consider what results the artisans intended to obtain and what resources they used to achieve them. In this respect, the analysed assemblage is generally golden in appearance, which contrast, for example, to a significant part of the greyish leaded bronze pieces from the visigothic Castiltierra necropolis (Segovia) (Rovira Llorens, 2017). The composition of the alloys may also reflect, at least in part, the wealth of those who adorned themselves with these objects. In Cortijo del Chopo, a significant amount of metallic artefacts with a high Zn content has been found in several nearby graves, along with other pieces of varied composition and from distant sources, as amber beads.

Finally, regarding the places in which the metals were produced and the objects made, to date we have no archaeological evidence that would give us an idea of the dimensions and characteristics of the production. To ascertain this, it would be necessary to study whether the metal finds of personal adornment documented in the numerous necropolises in the eastern part of Granada province, near Cortijo del Chopo, share the same metallurgical characteristics. We hope that in the future, material testimonies of this practice can be identified and published, thus contributing to our knowledge of metallurgy in the area.

CRediT authorship contribution statement

Elena Vallejo-Casas: Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Funding acquisition, Conceptualization. **Gisela Ripoll:** Writing – review & editing, Visualization, Supervision, Conceptualization. **Aaron Lackinger:** Writing – review & editing, Resources, Methodology. **Margarita Sánchez Romero:** Writing – review & editing, Funding acquisition. **Mercedes Murillo-Barroso:** Writing – review & editing, Writing – original draft, Visualization, Supervision, Methodology, Funding acquisition, Conceptualization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The material analysed is located in the Archaeological and Ethnological Museum of Granada (Spain). The data used has been included in the manuscript.

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Appendix A. Supplementary data

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