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ORIGINAL PAPER

The first metallurgy in the Pityusic Islands (Balearic archipelago, Mediterranean Sea)

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Abstract

The islands of Ibiza and Formentera (the Pityusic Islands in the Balearic archipelago, Spain) were one of the last insular contexts to be colonised in the Mediterranean. The first settlement occurred during the second millennium cal BCE, probably by continental Bronze Age communities. During the first centuries of occupation (ca. 2100–1400 cal BCE), local material culture is defined in terms of the Bell-Beaker/Dolmenic and First Naviform periods. The Pityusic Islands have no mineral resources for producing copper or bronze objects locally, so the presence of metal objects dated to these periods necessarily indicates exogenous contact. Seven metal objects have been found in five archaeological sites located in both islands. Archaeometallurgical research conducted on these objects reveals the economic behaviour of these first settlers in acquiring these resources. In this respect, aspects of this behaviour, such as technological patterns and trade dynamics, are analysed.

Keywords Bronze age · Pityusic Islands · Metal trade · Isolation · Island colonisation · Archaeometallurgy · Lead isotope analysis · XRF-ED

Introduction

The development of metallurgy and the importance of metals from the Chalcolithic and Early Bronze Age societies in the Western Mediterranean are evident from several perspectives. However, research has focused on major archaeological sites and contexts, such Los Millares, El Argar and the Bell-Beaker groups. Islands offer a number of advantages for studying prehistoric human societies (Evans 1973; Cherry 1990; Fitzpatrick 2004; Knapp and van Dommelen 2014; Dawson 2014; Cherry and Leppard 2017), especially as regards the possibility of identifying the influx of foreign elements.

The first human settlement on the Balearic Islands is widely accepted to have occurred between 2470 and 2210 cal BCE (Aramburu-Zabala and Martínez-Sánchez 2015; Bover et al. 2016; Cherry and Leppard 2018). On the Pityusic Islands (Ibiza and Formentera) (see Fig. 1), archaeological information for the early prehistoric settlers is dated to the end third and early second millennium cal BCE (Costa Ribas and Guerrero 2002; Ramis 2014) and is limited to just a few sites, including Avenc des Pouàs (Alcover 2008), Ca na Costa (Fernández et al. 1976; Topp et al. 1979; van Strydonck et al. 2005), Can Sergent (Costa Ribas and Fernández 1992), Cap de Barbaria II (Sureda et al. 2017a, 2017b), Cova des Fum (Topp 1988; Marlasca and López Garí 2015), Cova des Riuets (Marlasca 2008; López Garí et al. 2013) and Puig de Ses Torretes/Es Castellar (Costa Ribas and Guerrero 2002).

This surprisingly late occupation is usually understood in terms of environmental constraints, the Pityuses being resource-poor (Alcover et al. 1994; Costa Ribas and Benito 2000; Bofill and Sureda 2008; Cherry and Leppard 2018). Nevertheless, more than 50 Bronze Age sites (53) have been identified, although many of them have not been excavated. To date, archaeological research conducted on this archipelago and focusing on the prehistoric period has been scarce, but current projects related to the social and economic characteristics of the first human occupation are producing new data (Sureda et al. 2017a). The focus of this research concerns the first centuries of occupation and permanent settlement on the archipelago. This chronological period is related to the Bell-Beaker and First Naviform archaeological groups in the

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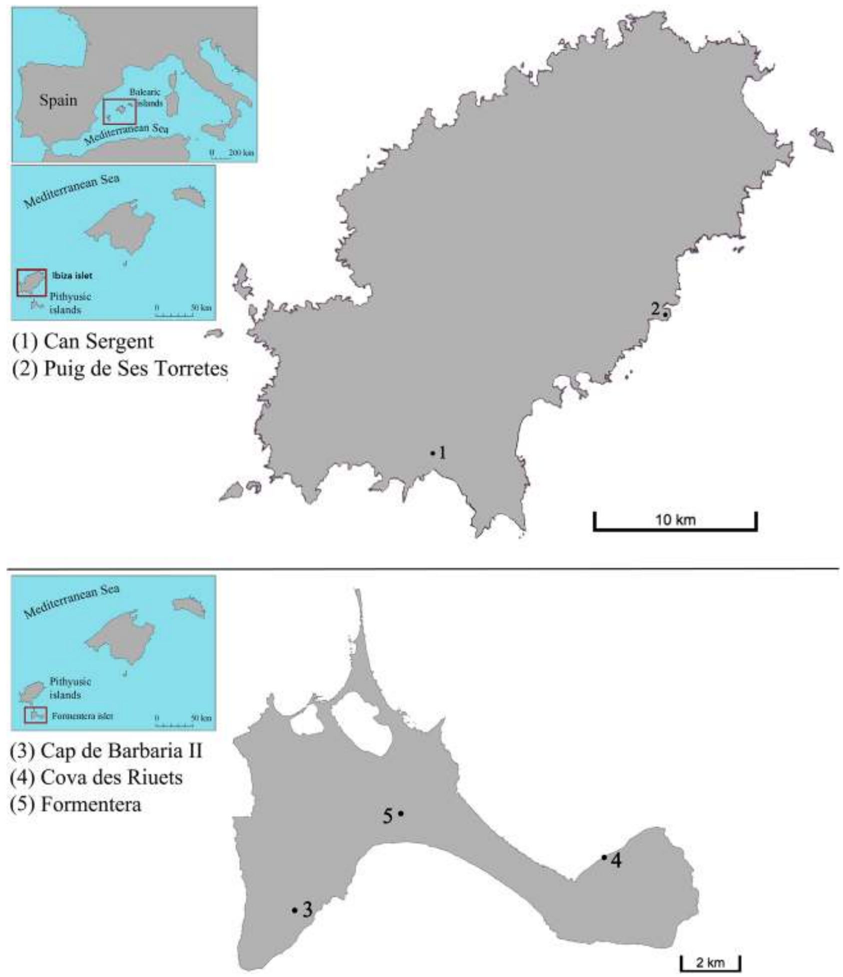

Fig. 1 Pityusic Islands map including the archaeological sites with objects studied in this paper

Balearics (Micó 2006) (ca. 2100–1400 cal BCE). During these centuries, the islanders' domestic activities were organised in villages of small houses, as well as in seasonally occupied caves. Various different types of funerary structure are distinguished, all related to rituals of burial in collective graves (mainly dolmens and natural caves) (Lull et al. 2004).

Materials and contexts

The calcareous Pityuses are entirely lacking in copper metalliferous ores; nonetheless, seven metallic objects (Fig. 2, Table 1) can be definitively attributed to the first centuries of their settlement.[1] These objects therefore represent an opportunity to explore the nature of the first influences, contacts and trade dynamics developed by the island settlers. These seven objects were located in five different archaeological contexts.

[1] One artefact from Puig de ses Torretes site, was also published as prehistoric (Costa Ribas and Benito 2000) but, after studing it, has been excluded because it seems to be related to the Punic nearest site of Cap des Llibrell (Sureda 2016).

Cap de Barbaria II

Cap de Barbaria II (CBII), an open-air village composed of at least three naviform habitations and other collective structures with different uses (storage, livestock shelter, workplace, etc.), is located on the south-western cape of the island of Formentera (Fig. 1) (Sureda et al. 2013; Sureda et al. 2017a); naviforms, similar to those in Majorca and Menorca, are boat-shaped structures constructed with a cyclopean technique (e.g. Juan and Plantalamor 1997; Salvà et al. 2002; Fornés et al. 2009; Salvà and Hernández-Gasch 2009; Anglada et al. 2013; Ramis and Salas 2014). The three naviforms at CBII do not differ from each other materially (size, construction technique and materials) and they were the focus of domestic activities during Balearic Bronze Age (including production, consumption and maintenance activities). New radiocarbon dating (Sureda et al. 2017b) attributes a first occupation of the site (phase 1) to ca.1662–1490 cal BCE (Fig. 3). Occupation continued until the village was abandoned in ca. 850 cal BCE (phase 2).

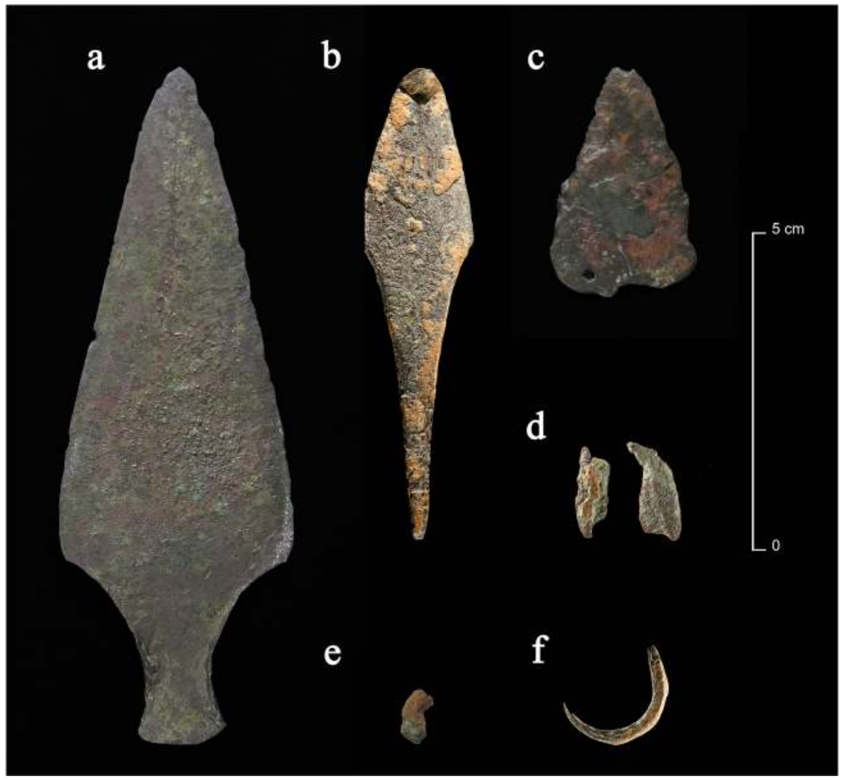

Fig. 2 (a–f) Metallic objects' photography from Pityusic Islands

Three metallic objects were found at CBII (phase 1) (Fig. 2(d–f)). From a functional point of view, they correspond to two laminar fragments (CBII/2012/116), a hook (CBII/2014/532) and an awl (CBII/2015/1125). The first finds were two laminar fragments in Naviform 9 (US 1.9.1.4), in association with very important evidence of household activities (Sureda et al. 2017a). Secondly, the fishhook fragment was found in Naviform 8 (US 2.8.1.3) and was also associated with household consumption residues. It has a rectangular section, rounded corners and a curved shape, which corresponds to the part of the bend and the beginning of the stem. Finally, the awl fragment has a quadrangular section and was found in Naviform 7 (US 1.7.6.1), along with an important group of associated consumption remains, mostly malacological.

Can Sergent

The Can Sergent site is located in the south of the island of Ibiza (Fig. 1). It was excavated between 1978 and 1979 and two structures, known as Can Sergents I and II (Topp et al. 1979, pp. 227–8; Costa Ribas and Fernández 1992, p. 308), were identified. The first occupation was a village comprising several huts and an oval-shaped perimeter wall; subsequently, an incineration necropolis dated during the Final Bronze Age was built in the same place (Micó 2005, pp. 81–82).

The small metal dagger (Fig. 2c) belongs to the first occupation of this site. The Can Sergent dagger is almost triangular and very small, with two perforations at its proximal end, where the rivets to support the handle, which have not been preserved, would have been located. According to its dimensions and shape, it seems to have been extensively used.

Table 1 Metallic object dimensions and weights

ID	Object	Dimensions (mm)	Weight (g)
CBII/2012/116	Laminar fr.	15 and 12 long by 5 and 4 wide; 1 thick	0.32
CBII/2014/532	Hook fr.	13.6 long, 17.4 wide, 1.8 thick	0.46
CBII/2015/1125	Awl fr.	8.3 long, 3.4–3.9 wide, 2.8 thick	0.25
Can Sergent	Rivet dagger	54 long and a maximum 24 wide	4.0
Cova des Riuets	Awl fr.	6 long, 3 thick	0.5
Ibiza 1907	Dagger	117 long, 40 wide and 2.5 thick	40.0
Formentera	Arrowhead	73 long; 17.7 maximum width, thick: 1.8 (pedestal), 3.4 (middle) and 2.4 (blade)	11.97

Fig. 3 Location of all metallic objects into Cap de Barbaria II archaeological site

Cova des Riuets

Cova des Riuets, a cave on the north-western side of La Mola, on the island of Formentera (Fig. 1), was discovered archaeologically in 1974 (Trias and Roca 1975) and excavated in 2002. This intervention led to the find of a very complete archaeological repository, including two radiocarbon dates (2011–1886 and 1949–1780 cal BC), attesting a wide range of domestic activities (Marlasca 2008; López Garí et al. 2013).

Among the objects found, we can highlight a metal awl fragment. It was found in the area of the cave entrance, in a secondary position. It consists of a small fragment of quadrangular section, corresponding to the non-functional part of the implement.

Ibiza 1907

This is the name under which an artefact kept in the Archaeological Museum of Ibiza and Formentera since 1907 has been published. It was found on the island of Ibiza, with no more precise information available (Sorà 1944). It is particularly surprising for its preservation and it can be typologically associated with some of the types of Early Bronze Age or Chalcolithic artefacts found in Iberia (Delibes de Castro and Fernández-Miranda 1988, p. 86).

It is a knife or dagger (Fig. 2a) with a long triangular blade. It also bears what appear to be traces of hammering on the edge of the blade, as well as some marginal burrs, apparent for decorative purposes, which form a small central rib at its intersection near the tip.

Formentera

Recently (Sureda 2018), a chance find, apparently without context, was recovered during farm work to the south of the town of Sant Ferran in Formentera (Fig. 1).

The object corresponds to the so-called Palmela arrowhead type (Fig. 2b). Lengthwise, it has a blade with an oval morphology that is slightly pointed at the end and has an elongated peduncle in the middle, which is rectangular and narrows progressively. This specimen has a slightly deformed tip, possibly due to an impact on a harder surface. As a whole, it is a very stylish object and also has lines perpendicular to the axis of the peduncle that can be associated with the fitting of the haft.

Analytical methods

Chemical analyses

The chemical compositions of all items were analysed with X-ray fluorescence (pXRF) using Innov-X Alpha series equipment with a silver anode and a SiPIN detector (< 230 eV FWHM at 5.95 keV Mn K-alpha line). The X-ray tube was operated at 35 kV, 20 μA using a 2-mm aluminium filter. The fundamental parameter (FP) calibration was adjusted on the basis of the results of the analyses of a set of 18 different metal and copper-based alloy standards (particularly UE10-1 and UE15 from BNF Metal Technology Centre for bronze and 36X CAS3 from MBH Analytical Ltd. for arsenical copper). The detection limits were established at 0.02% for Fe, Ni, Co, Zn, As and Pb; 0.05% for Sn and Bi; and 0.15% for Ag and Sb. The margins of error in the measures are as follows: > 0.5% of the value for percentages greater than 50%; > 2% for content greater than 5% in any other element; > 40% in the content less than 1% of the detected elements. The values are expressed as a weight percentage (%) for each of the elements detected (ND = not detected). All the samples were cleaned mechanically on the surface to avoid patina effects.

Two of the artefacts (Ibiza 1907 and the Can Sergent dagger) had been previously analysed. Those analyses, distinguished by the letters AA in their ID, were carried out with X-ray fluorescence using a KeveX mod 7000 with an Am241 source. The detection limits were established at 0.01% for Fe, Ni, Cu, Zn, As, Sn and Pb; 0.001% for Ag and Sb. Other features for these specific equipment can be consulted in Rovira et al. (1997) or Rovira and Montero-Ruiz (2018).

Metallographic analyses

Metallographic analyses were performed using optical microscopy (Leica DMLM) under bright field (BF) and dark field (DF) illumination. All samples were prepared and polished following standard laboratory procedures (Scott 1991; Rovira and Gómez Ramos 2003). All the samples studied using this technique correspond to copper-based metallic elements. They were etched using a reagent with ferric chloride and hydrochloric acid in an alcohol solution (exact composition: 10 g ferric chloride, 120 ml 96° ethyl alcohol and 30 ml hydrochloric acid), according to Scott (1991, p. 72). Photomicrographs of the samples were taken with a Leica DFC480 digital camera. The structural examination of the metal sections was performed working with magnifications of between × 50 and × 1000.

Lead isotope analysis

The samples for lead isotope analysis (LIA) were obtained by drilling the metal with a 1.5-mm-diameter bit. Mass spectrometric lead isotope analyses were carried out at the Geochronology and Geochemistry SGIker Facility at the University of the Basque Country UPV/EHU (Spain). Pb isotopic ratios were obtained using a high-resolution multicollector ICP-MS instrument (Neptune, Thermo Fisher Scientific). For the Pb isotope analyses, an aliquot of about 0.010–0.020 g was digested overnight in HNO_3 and evaporated to dryness. The residue was taken in HBr and Pb was subsequently isolated by conventional ion-exchange chromatography (AG1-X8 resin in HBr and HCl media). The recovered lead was evaporated to dryness, dissolved in 0.32 N HNO_3 and diluted to a final concentration of 150–200 ppb. Lead isotope ratios were measured on the MC-ICP-MS and the mass fractionation internally corrected after the addition of thallium isotopic reference material NBS-997. The detailed protocols are similar to those described by Chernyshev et al. (2007). The accuracy of the results was confirmed by repeated analyses of lead isotopic reference material NBS-981.

Microhardness tests

Microhardness tests describe the resistance of metals to deformation. There are several scales that measure this property, but that most commonly used in historical metallurgy is the Vickers Scale (Scott 1991, p. 77). In order to carry out these studies, the Remet HX-1000 microhardness durometer of the MICROLAB laboratories in Madrid was used. The Vickers procedure uses a diamond pyramid indenter that is applied perpendicularly to the surface of the sample under a load of between 200 and 500 g.

Results

Metals and alloys

The chemical composition data from all seven artefacts indicate a composition of copper, arsenical copper and copper-tin alloys (Table 2). The main metallic impurities identified are arsenic (As), iron (Fe) and lead (Pb). However, other objects present also included nickel (Ni), zinc (Zn) and bismuth (Bi). In the bronze objects, the tin (Sn) content is relatively low (2.9–9.9%) and it is not standardised.

Microstructures

Four metallography and microhardness tests were made to elucidate metallurgical technological information. This corresponds to the three objects from the Cap de Barbaria II site (CBII-116, CBII-532 and CBII-1125). From a technological point of view, metallographic observations reveal the activities of hammering and annealing (see Figs. 4, 5 and 6).

Table 2 XRF chemical analysis results (values are normalised in wt%). *ND* not detected

ID analysis	Piece	Site	Fe	Ni	Cu	Zn	As	Ag	Sn	Sb	Pb	Bi
AA1334	Dagger	Can Sergent	0.21	0.04	89.07	ND	ND	0.05	9.93	0.04	0.12	ND
PA22792	Laminar (fr.)	Cap de Barbaria II	ND	ND	98.84	ND	1	< 0.15	ND	< 0.15	0.16	ND
PA24252	Awl (fr.)	Cap de Barbaria II	ND	ND	95.8	ND	1.18	< 0.15	2.92	< 0.15	0.1	ND
PA23512	Hook (fr.)	Cap de Barbaria II	ND	ND	97.2	ND	2.35	< 0.15	ND	< 0.15	0.42	ND
PA22804C	Awl (fr.)	Cova des Riuets	0.4	ND	93.22	ND	0.04	< 0.15	6.35	< 0.15	ND	ND
AA1343	Dagger	Ibiza Indet.	0.15	0.03	97.14	0.13	1.76	0.006	0.03	0.018	0.1	ND
PA24251	Palmela arrowhead	Formentera	0.26	ND	97.8	ND	1.68	< 0.15	ND	< 0.15	0.1	0.16

From the laminar fragment (2012/1/116), which basically consists of copper, it can be seen that it was produced by mechanical deformation, shown by the parallel bands of its structure, which are already perfectly visible in very few increments (Fig. 4a). These deformation bands were produced after casting (C) due to hammering. Besides, under greater magnification (Fig. 4b), the presence of some incipient grain-size differences and some twin lines can be observed, which denotes the application of heat, or annealing (A), during the forging (F). However, this possible step was very low in intensity, as it was not possible to recrystallise the metallic structure. In the same way, the absence of strain lines may suggest hot-working during this process. Otherwise, the presence of numerous air bubbles in the interior of the lamina, almost without deformation, seems to indicate that the forging was also not very intense. Finally, the microhardness tests show average values of 79.8 HV (Table 3).

The hardness values are consistent with the technological process we have seen for the object, a copper base with 1% arsenic (As), which has been identified as forging and subsequently a mild annealing (C + F + A). For worked copper metals with 1.8% As, Scott (1991, p. 83) places the microhardness between 65 and 70 HV, while that of cold-worked pure copper is between 100 and 120 HV. In this respect, the low levels of As allow us to place object 2012/116 between the two previous measurements, although it must be borne in mind that the annealing of worked metals significantly reduces their hardness (50–60 HV). In this case, the low intensity of the annealing would not have significantly reduced the hardness of the metal.

In the case of the hook (2014/532), which is composed of arsenical copper (2.35% As), it was possible to sample the stem. From its microstructure, we can see the remains of a possible dendritic structure (darker orange strips) (Fig. 5a–c), all greatly deformed by later forging. There are many bubbles, possibly caused by gases during solidification. Observations on this object suggest that it may have been subjected to annealing homogenisation before the mechanical treatment was started. The dendritic remains, and the absence of granular structure, indicate that the annealing time was insufficient to achieve complete homogenisation. Later, the initial object, possibly an elongated bar, was worked mechanically with great intensity, until the artefact obtained its current curved shape. This intense forging, represented by strain lines, took place with the metal cold, apparently without complete annealing in this phase of the process, as the granular structures, typical of this type of work, are not present either. There are also some possible microporosities and corroded areas, which, from careful observation in large magnifications and in BF and DF (Fig. 5c, d), appear to be enriched in lead oxides, probably corresponding the 0.42% detected in XRF-ED.

However, a production process based on C + A + cold F in arsenical copper objects is difficult to certify, because after casting, signs of dendritic structure are scarce with irregular edges (Rovira and Gómez Ramos 2003, p.16). The presence of these darker and narrower bands may be related to the percentages of arsenic in the object.

Finally, microhardness tests were carried out that place it at mean values of 119.4 HV. These values are consistent with the technological process we have seen for the artefact, which is composed of copper with As levels of 2.35% As, in which an intense cold wrought work was identified that hides a possible uncompleted annealing for a previous homogenisation (C + A + cold F). For copper metals with As levels of 2.6% and worked in cold, Scott (1991, p. 83) places a microhardness value of 150–160 HV. With this intense work, which gives an average hardness value of 119.4 HV, it would have acquired a good equilibrium between the hardness and flexibility needed to perform its function.

On the other hand, the awl fragment, 2015/1125, which it was possible to analyse though metallography (Fig. 7), as well as longitudinal section (Fig. 6), has a full microstructure of displacement lines due to the intense forging to which the object was ultimately subjected.

From the longitudinal section, it is necessary to point out what appears to be a granular structure (also visible in the cross-section), partially broken by the cold forging, where there are only some grain limits, also visible from the alignment of many of the slip bands of the forging itself. Observation of the zones where the initial grain is best preserved allows us to assume that these were produced by an annealing activity that followed the smelting process. In this

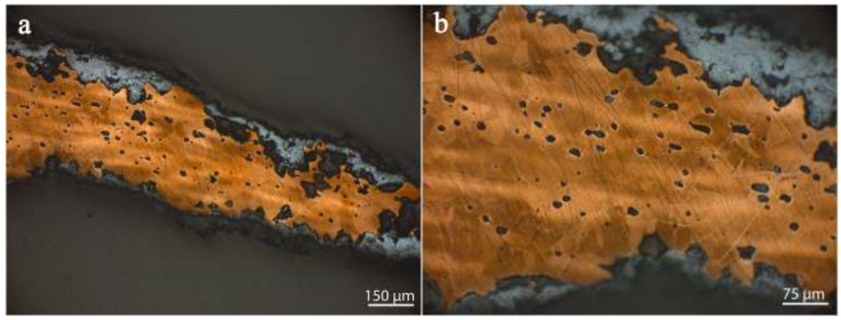

Fig. 4 Microstructure, in different scales, of metallic laminar fragment (2012/1/116). **a** × 50 magnification. **b** × 100 magnification

respect, the low percentages of this alloy could possibly explain the absence of Sn segregation, as, although the metal would have cooled quickly, there would have been sufficient time to homogenise them.

This can be appreciated from a more careful observation of the cross-section, as the forging affected the surface, also deforming all the dendrites, as well as some areas of copper oxide (blue in BF). This forging took place with the metal already cold and affected the entire structure, as can be seen in the two cuts made, taking place from the four sides of the object to give the tool its quadrangular section. Unfortunately, it was not possible to carry out a more careful study of the SEM-EDX that would have allowed us to clarify the nature of the rest of the inclusions and segregates presented by the sample.

Finally, in this last section cut, the microhardness tests placed it at mean values of 147.4 HV. These values are consistent with the technological process we have seen for the artefact, which is an arsenical bronze with levels of 2.92% of Sn and 1.18% of As, in which intensive cold forging has been identified, which conceals a possible homogenisation prior to forging (C + A + cold F).

Provenance considerations

Lead isotope ratios were analysed in six samples. Information on the origin of metals was obtained by comparing not only the lead isotope ratios of the artefacts, but also their elemental compositions and the geochemistry of the ores from the deposits selected from literature by their lead isotope ratios. For this reason, following the leading isotope data interpretation methodology (Hunt 1998; Gale and Stos-Gale 2000), we compared the results from Bronze Age Pityusic objects with various ores and artefacts from the Mediterranean and Europe.

Different isotopic data were compared with Pityusic objects, allowing us to rule out a provenance from several major metallurgical zones, including most of the south-western Spanish ores such as Linares, Osa Morena and Alcudia. The majority of Sardinian, European and African ores, as well as others, such as those from south-eastern Spain, have different isotopic signatures. Other ores and groups of artefacts are more consistent with some of the Pityusic objects. For instance, they have been compared to copper minerals from Menorca (Hunt et al. 2013), south-western Sardinia (Stos-Gale 1999; Begemann et al. 2001), the Catalonia-Pyrenees

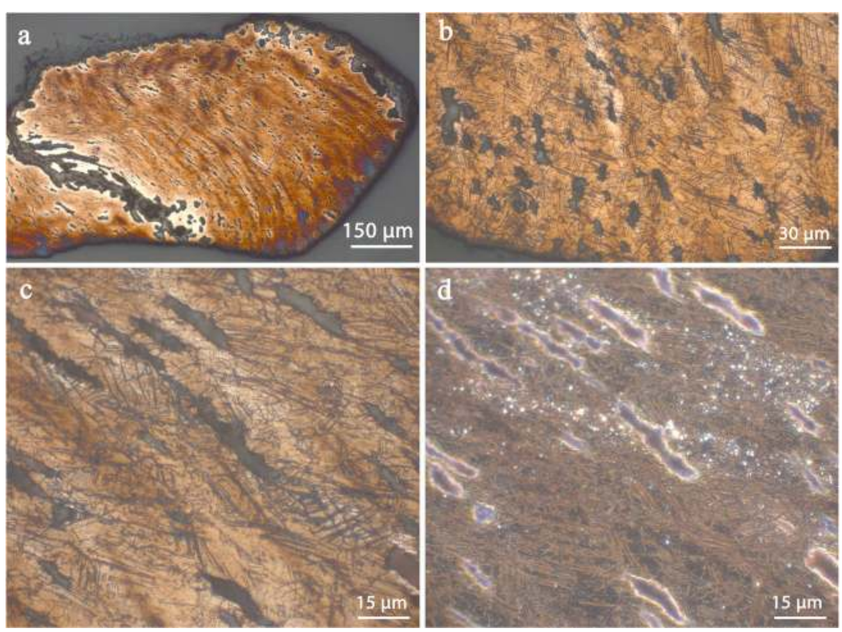

Fig. 5 Microstructure, in different scales, of metallic hook fragment (2014/532). **a** × 100 magnification. **b** × 500 magnification. **c** × 1000 magnification BF. **d** × 1000 magnification DF

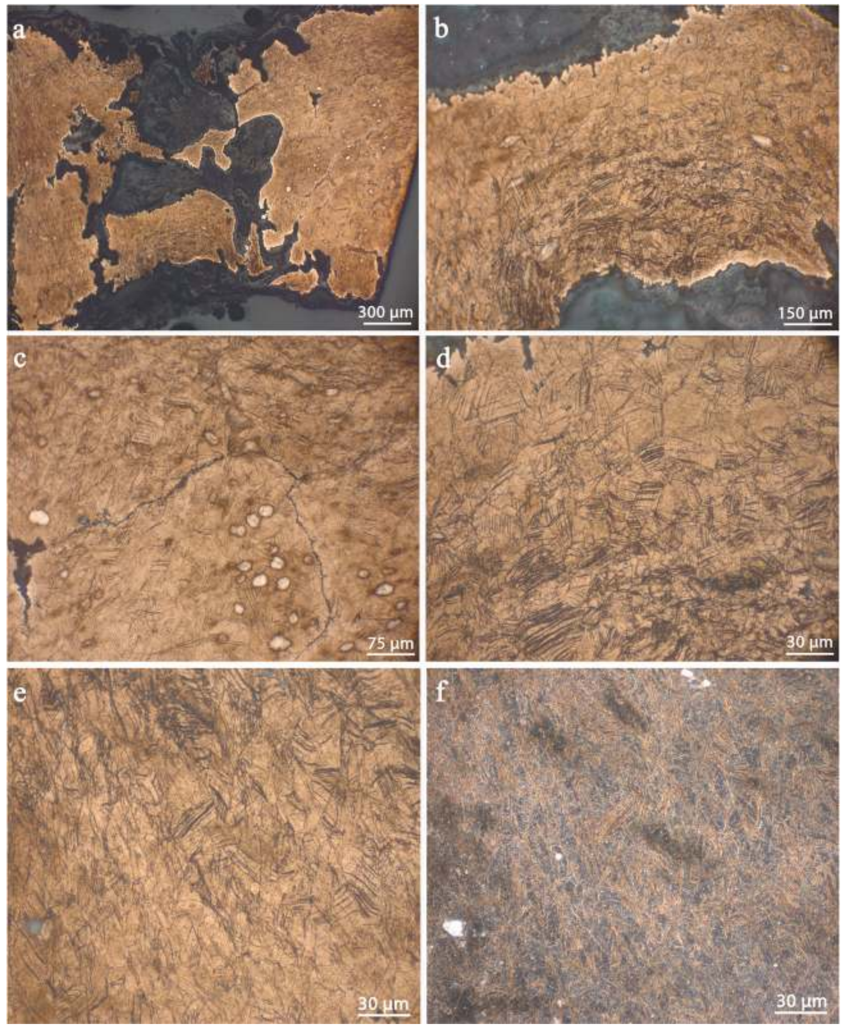

Fig. 6 Microstructure, in different scales, of metallic awl fragment (2015/1125) in longitudinal disposition. **a** × 50 magnification. **b** × 100 magnification. **c** × 200 magnification. **d** × 500 magnification. **e** × 1000 magnification. **f** × 1000 magnification DF

region, Almería and the French Pyrenees[2] (Munoz et al. 2016). Also, reliable objects from the Balearic Islands (Stos-Gale 1999), the Early Bronze Age in the Catalonia-Pyrenees region and the Launac culture in Languedoc-France (Guilaine et al. 2017) have been used to support or reject provenance hypotheses.

In a first approach to scatterplots (Fig. 8), different artefacts, such as the hook and laminar fragment from Cap de Barbaria II, appear clearly differentiated from the other objects, which are more grouped. Taking all this into account, the lead isotope results (Table 4) show a heterogeneous distribution for Pityusic objects.

The laminar fragment from CBII (2012/116) seems to be compatible with the ores from Menorca (Fig. 8). This can be supported by the results for different finds from the Menorcan burial site of Cova des Mussol (Stos-Gale 1999), which are very similar in isotopic terms, especially a chisel also found in that cave (MU-S4a-M-58). Nevertheless, the presence of As in this object appears to be higher than that of the Menorcan ores (Rovira et al. 1991; Hunt et al. 2013) where As rarely exceeds 1% values.

On the other hand, the Palmela arrowhead from Formentera (Sureda 2018) appears to be compatible with the ores from Calabona (NW Sardinia). However, the differences in geological composition between the object (Bi and Pb impurities) and the original ores (Cu-Fe) suggest that this provenance hypothesis can be ruled out. Moreover, we have no evidence of the presence of Palmela-type arrowheads in Sardinia or any other evidence of contact between the two regions during this period. However, comparing our isotopic results with other artefacts from the Launac culture shows compatibility with artefacts from the Marseilles region (Guilaine et al. 2017).

A similar situation can be applied to the awl fragment from CBII (2015/1125), the results of which can be related to a few ores (Les Ferreres and Rocabruna mines) and smelting

[2] Most of the isotopic data involving Iberian artefacts and ores were consulted in collaboration with Ignacio Montero and the "Archaeometallurgy of the Iberian Peninsula project" database.

Table 3 Microhardness test results of metal objects from the Cap de Barbaria II site

Analyse ID	Piece ID	Type	Measures	Value Max.	Value Min.	Average
PA22792	2012/116	Laminar fr.	4	81.5	76.3	79.8
PA23512	2014/532	Hook fr.	4	134.5	108	119.4
PA24252	2015/1125	Awl fr.	6	163	138.5	147.4

remains (Bauma del Serrat del Pont) from the Eastern Pyrenees region, which have a similar isotopic signature (Fig. 8). Thus, a Pyrenean origin for this metal can be suggested.

Data corresponding to other artefacts, such as the Ibiza 1907 dagger or the Can Sergent rivet dagger, are more difficult to link to a single exclusive provenance area. In these cases, the LIA results are closer to the Menorcan isotopic field, as well as to some artefacts in the Launac assemblage. The high levels of As in the Ibiza 1907 artefact (1.76%), which is scarce in Menorcan ores, make a Balearic origin more plausible just for the Can Sergent rivet dagger, however, other unknown copper resources without arsenic could be also an option.

Finally, the results for the CBII hook (2014/532) do not coincide with practically any of the previously mentioned ores or groups of objects (Fig. 8).

In short, we suggest two different possible provenances for some early Pityusic metals: firstly, the Eastern Pyrenees/Languedoc area linked to Palmela arrowhead, the CBII awl (CBII2015/1125) and the Ibiza 1907 dagger, and secondly, the CBII laminar fragment (CBII2012/116) and Can Sergent dagger, metals that are related to Menorcan copper ores.

General discussion

The first human presence in the Balearic Islands is dated between 2470-2210 cal BC (Alcover 2008; Aramburu-Zabala and Martínez-Sanchez 2015; Bover et al. 2016) and entailed a huge effort in establishing a permanent settlement. In this respect, aspects such as aridification, low sedimentary conditions and poor biodiversity (Alcover and Muntaner 1985; Alcover et al. 1994; Cherry and Leppard 2018) were natural processes the first settlers had to deal with (Sureda et al. 2017a). Moreover, imported domesticated animals, cereals and other species had to be introduced to the island to guarantee the prosperity of the communities (Ramis 2017). As we know, metal objects were not a priority during these first phases of human colonisation. This was probably due to multiple factors, including the possibility of maintaining these industries by exploring local natural resources (cooper ores). Because of this late chronology, and as suggested by all the different surrounding mainland societies, it has been proved that the first Balearic colonisers had the metallurgical and technological knowledge to develop a local industry (at least in Mallorca and Menorca). In this respect, the evidence of copper mining at Illa den Colom in Menorca, dated to ca. 1800–1600 cal BC (Hunt et al. 2013), seems to prove this hypothesis. There are also other evidences such as small local copper productions using simple open-fire structures, often using pottery vessels as reactors for smelting the ores (Rovira and Renzi 2017), which have been identified at such Mallorcan sites as Son Matge (Waldren 1979) and Arenalet de Son Colom (Ramis et al. 2007). According to this data, the first Balearic settlers succeeded in developing local metallurgical industries a few generations after their permanent establishment.

In this regard, the absence of ore evidences at any of the Balearic settlement sites is remarkable. In fact, this suggests that the reduction of the copper ores would have taken place at the mines or at other places distanced from the settlements. In this respect, the survey information from the Serra de Tramuntana copper ores (Mallorca) (Alcover et al. 2007; Ramis et al. 2005) and the excavations at the Menorcan mines of Illa den Colom (Hunt et al. 2013; Llull et al. 2013; Salvà et al. 2014) show that there were sufficient copper resources in Mallorca and Menorca for them to be exploited in prehistory. In general, and while waiting to be able to confirm these hypotheses with more detailed studies and new data from the mining contexts, the situation of Mallorca and Menorca could be a case of copper exploitation on a local level, comparable to that found in the Priorat area of Catalonia (Rafel et al. 2009). Regrettably, we do not as yet have any lead isotopic analyses of the remains of this first metal production.

However, the case of the Pityusic Islands was substantially different in terms of the inexistence of local copper minerals and perhaps this particular circumstance can be linked to the emergence of local natural resource exploitation strategies, as recently discussed (Sureda et al. 2017a). The scarcity of metal artefacts, and other exogenous materials like flint, suggests in general terms a high degree of isolation during those first centuries of settlement. This factor is essential for analysing all the different aspects involving metal artefacts such as their production technology, use and social significance.

Pityusic metals present a majority of copper/arsenical copper (4) over bronze (3) artefacts, as is observed in these chronologies in most Mediterranean regions. The first bronze artefacts are documented in the Balearics in relation to early colonisers ca. 1800 cal BC at the Aigua Dolça dolmen site (Guerrero et al. 2003). Regarding the main impurities detected on Pityusic objects, special attention must be paid to those artefacts with an As content. In fact, the intentionality of As

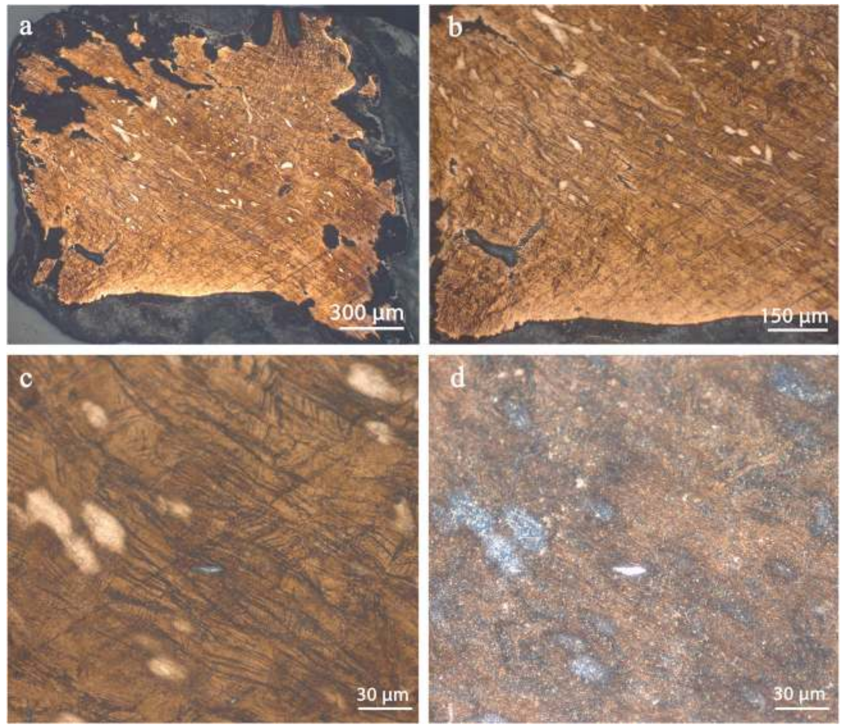

Fig. 7 Microstructure, in different scales, of metallic awl fragment (2015/1125) in cross-section. **a** × 50 magnification. **b** × 100 magnification. **c** × 500 magnification BF. **d** × 500 magnification DF

presence in metal objects has caused one of the most intense debates in Iberian Peninsula archaeometallurgy studies in recent decades (as well as in Europe and Mesopotamia) (i.e. Charles 1967, 1980, 1985; Telycote et al. 1977; Telycote 1991). It is now widely accepted that As additions are naturally incorporated during the transformation of ore into metal (Rovira 2004, pp. 17–19), as was documented, for example, in the Chalcolithic site of Almizaraque (Almería, Spain) (Delibes et al. 1989, 1991). Moreover, as suggested in another paper (Sureda et al. 2017a), the isolation of the Pityusic populations also influenced their economic behaviour, causing them to continue to use exogenous materials, such as flint tools and cores, until they wore out. In the specific case of metal artefacts, it is notable that all the objects found in archaeological contexts, such as Cap de Barbaria II, are very small and they represent only a total amount of 57.5 g of metal. This general scarceness of metal might have influence on long-term use of artefacts. In fact, as we have seen in their geochemical composition and their As values,[3] it can be suggested that they were not recycled in any significant way. Besides, Can Sergent's rivet dagger was extensively sharpened, reducing progressively its dimensions until it was no longer of use, revealing a preference for long-term use rather than recycling. Other impurities, such as Zn and Bi,[4] identified in Ibiza 1907 and Formentera artefacts, are not represented in the other objects and a different mineralogical origin can be suggested for these metals. The technological processes involving these objects may have been influenced by the isolation, although it is difficult to determine whether or not the artefacts were produced in the Pityusic Islands and their interpretation may be different in any case. According to this, it is remarkable that most of the artefacts represented in the Pityusic Islands correspond to externally recognised types (Delibes de Castro and Fernández-Miranda 1988) such as, for instance, the Palmela arrowhead or the two daggers. It is important to explain that these objects were probably not produced on the islands, as we have found no evidence of casts, mineral reduction or smelting processes.

With regard to alloys, we do not have enough data to evaluate the control of copper and tin alloys at that time, although it appears clear that there was no standardisation of the additions in our three bronze artefacts. This situation is comparable to that in the rest of the Balearic Islands, as well as in the nearby coastal and mainland regions of the Iberian Peninsula (Rovira 2005). As we can see over the three metallographic studies of the Cap de Barbaria II site, simple technological processes were followed in making these artefacts (C + cold F + A or C + A + cold F). For instance, we can compare the case of the CBII awl to similar examples of these types of alloys that are close in chronology and geography, such as those studied at the Argaric site of Cerro San Cristobal (Aranda et al. 2012). At that site and others, such as Cerro de la Encina and Peñalosa, several studies have been carried out on the hardness of objects with arsenical bronze compositions (same as awls of this study). In the case of the awls

[3] It has been proven experimentally that recycling may cause a loss of As values in metal objects (Lechtman and Klein 1999).

[4] Ni could also be included but the results identified in Table 2 (with KeveX equipment) are under the detection limits of the Innov-X Alpha series equipment (pXRF) so they cannot be compared.

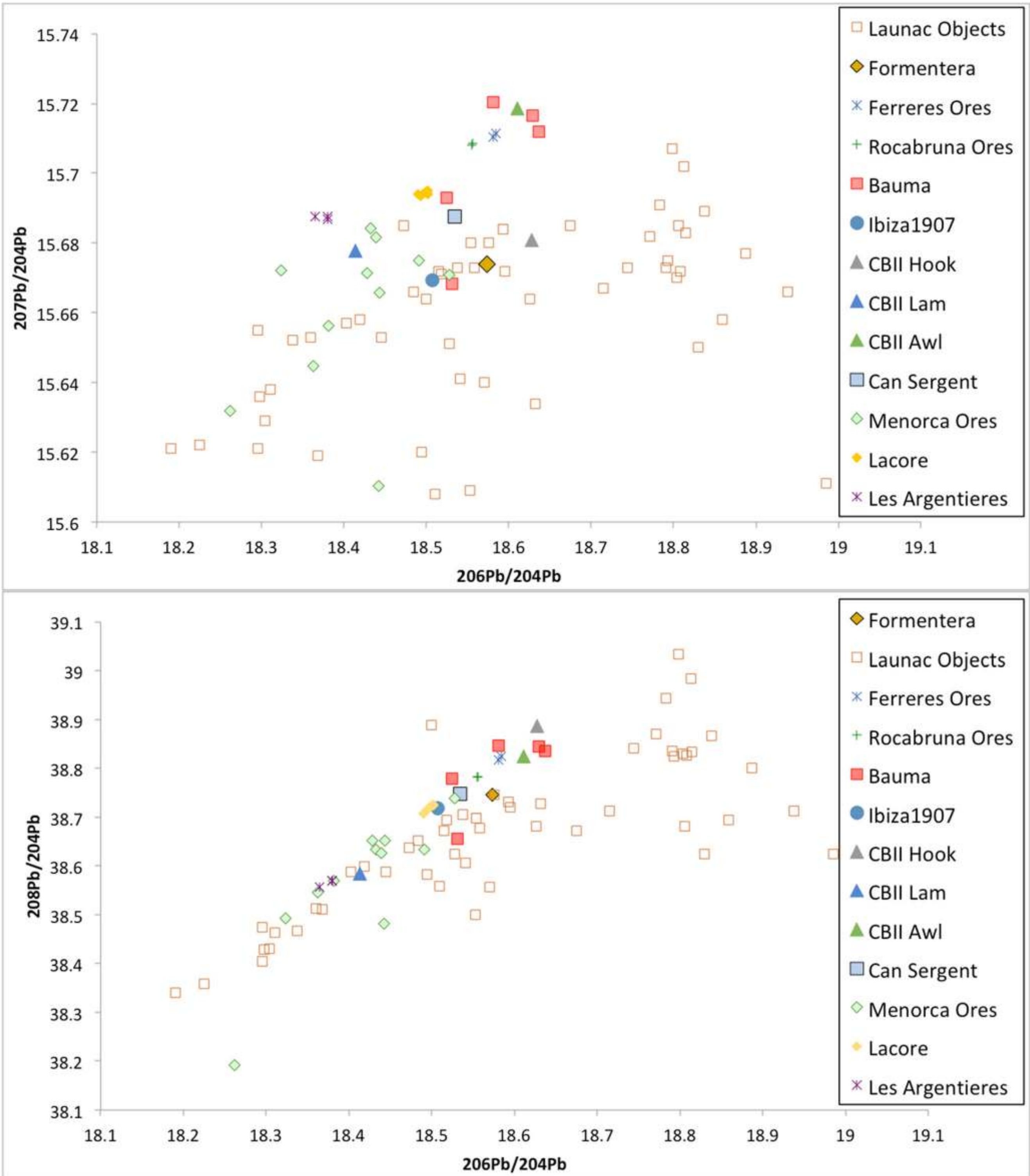

Fig. 8 Scatterplots of lead isotope analysis results of Pityusic metal objects

studied, the hardness is between 160 and 200 HV, regardless of their composition, which is greater (in As/Sn %wt) than that of our artefacts. This difference must be linked to the production process with which these objects (C + cold F + A + cold F) were produced, which was different to that identified for the Cap de Barbaria II awl. Other examples of contemporaneous Mallorcan artefacts (awls, bracelets and knives) (Salvà 2013, p. 513) show similar metallurgical work. However, the intensive working to which this object was subjected gives it an average hardness of 147.4 HV, revealing a good mastery of hammered forging techniques and making it a good working tool with a remarkable drilling capacity.

Table 4 Lead isotope results of Pityusic metal objects

Site	Description	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{204}Pb$	$^{208}Pb/^{204}Pb$	$^{208}Pb/^{206}Pb$	$^{207}Pb/^{206}Pb$
Cap de Barbaria II	Laminar fr.	18.4134	15.6777	38.5838	2.09542	0.85143
Cap de Barbaria II	Hook fr.	18.62792	15.68084	38.88748	2.087591	0.841792
Cap de Barbaria II	Awl fr.	18.61068	15.71853	38.82504	2.08617	0.8445973
Can Sargent	Dagger	18.53411	15.68764	38.74728	2.090593	0.84642
Ibiza 1907	Dagger	18.50717	15.66933	38.71873	2.092094	0.8466627
Formentera	Palmela	18.57362	15.67492	38.74521	2.086034	0.8439345

As far as external contacts represented by metallic artefacts are concerned, lead isotope analyses confirm the peripheral position of the Pityusic Islands in the trading networks throughout this period (2100–1400 cal BC). Two different zones have been proposed as possible origins for some of the objects analysed, which probably correspond to different trade networks.

Firstly, the Eastern Pyrenees and Languedoc is proposed as the area of origin for the Palmela arrowhead, the CBII awl (CBII2015/1125) and the Ibiza 1907 dagger. This is one of the areas historically proposed as the origin of the first Balearic colonisers (e.g. Ramis 2010). In fact, the archaeological finds associated with the early settlers show several close parallels with these mainland populations (Claustre et al. 2002; Martín and Mestres 2002) and this has been interpreted as the influence of those who remained in the source region. In this respect, aspects such as the Beaker pottery (Waldren 1982), the settlement structure (Fernández-Miranda 1993), megaliths (Plantalamor 1976) and the presence of early tin alloys (Rovira et al. 1991) all suggest a close relationship between the early settlers and the Languedoc region of southern France and the north-eastern Iberian Pyrenees (e.g. Lull et al. 2004; Alcover 2008). According to this, our results can be interpreted as confirmation of this provenance hypothesis, if we consider that these objects arrived with the first settlers, taking part in a delayed migration process. They may also be evidence of a continued trade relations between these first settlers and the mainland during the following centuries.

Secondly, we have to consider that the provenance of the CBII laminar fragment (CBII2012/116) and the Can Sergent dagger metal are linked to Menorcan copper ores. It is accepted that during the Chalcolithic and Epicampaniform periods, there were fluid relations between the islands of Mallorca and Menorca, due to the contemporaneous emergence of the Naviform culture (e.g. Lull et al. 1999; Calvo Trias et al. 2002) with its typical house structures. This is considered to have been the first archaeological culture in the Balearics that can be clearly differentiated from those on the mainland (Salvà et al. 2002; Lull et al. 2004; Ramis 2010). These contacts probably involved all the Balearic Islands, but they were more sporadic between the Pityusic Islands and the rest of the archipelago. This factor is important for explaining why we also find naviform constructions and similar material culture in the whole of the Balearic archipelago during the Bronze Age (Sureda et al. 2013). It may also explain the different historical and archaeological development between the island groups during the rest of the Bronze Age, which is clearly represented in terms like funerary traditions.

Conclusion

Metallurgy was one the elements imported with first human occupation of the Balearic and Pityusic Islands, which did not occur until the end of the third millennium cal BCE. Nevertheless, once a stable population had been settled, the Pityusics and the limited ecological biodiversity (without copper ores and other resources), as well as the isolation, led to adaptations in the economic activities of these prehistoric settlers.

This study has allowed us to characterise the socioeconomic strategies related to the Pityusic settler's metallurgy from ca. 2100 to 1400 cal BCE, as an important element for analysing their technological features and external contacts and influences.

Based on technological studies, it is possible to suggest intensification in the use of metal objects, as well as a preference for long-term use rather than recycling. Nevertheless, considering the absence of raw materials and the relative isolation, local production is only considered as a hypothesis for small artefacts like awls and hooks. The rest of objects, bigger and with well-known typologies, were probably made elsewhere and then imported on the islands.

According to this, there is a clear connection between the early Pityusic settlers and the Pyrenees-Languedoc societies, as suggested by lead isotope analyses, as well as archaeological parallels. Besides, some of the artefacts could have arrived to the Pityusics in relation with the colonisation process, as the case of the Formentera arrowhead, and may be considered as a new argument for considering their provenance from Pyrenees-Languedoc region. However, these contacts had also continued in the following centuries, as the CBII awl associate chronology suggests (ca. 1662–1490 cal BCE). On the other hand, it has been shown that after the settlement had been established and consolidated, contacts were also established between the different islands of the archipelago. These contacts are attested by the presence of Menorcan metal in the Pityusic Islands and also by the contemporaneous emergence of the Naviform culture. Regarding the chronology of some common artefacts as the rivet daggers, the exploitation of Menorcan copper ores and their presence in well-dated Pityusic sites as CBII, this contacts could have started between ca. 1800 and 1500 cal BCE.

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