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ORIGINAL PAPER

Sant'Imbenia (Alghero): further archaeometric evidence for an Iron Age market square

M. Clemenza[1,2] · B. Billeci[3,4] · M. Carpinelli[3,5] · M. Ferrante[6] · E. Fiorini[1,2] · G. Gasperetti[4] · S. Nisi[7,8] · P. Oliva[3,9] · V. Sipala[3,5] · P. R. Trincherini[8] · I. M. Villa[1,10,11] · M. Rendeli[3,5]

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Abstract
Lead isotope compositions were determined for 18 metal objects from the archaeological site of Sant'Imbenia, NW Sardinia, dating to the end of the ninth century BCE onwards. The provenance of some objects is unambiguously traced to SW Sardinia; other objects could derive either from central Sardinia or the Iberian coastal ranges. The variety of the provenances attests to a wide trade network that spanned the entire island of Sardinia and extended to the Iberian sites.

Keywords Iron Age Sardinia · Sant'Imbenia · Alghero · Lead isotope analysis · Provenances

Introduction

The archaeological site of Sant'Imbenia in NW Sardinia (lat. 40°37′21.48″ N; long. 8°11′47.74″ E)[1] lies in a sheltered natural harbour that has been called Porto Conte since the Middle Ages. It is located 10 km to the WNW of Alghero and at present is a marshy and sandy shallow coastal area, protected from the prevailing wind (Mistral). About 100 m inland of the present-day coastline, a *nuraghe* was built during the fourteenth century BCE, surrounded by a small number of huts. The *nuraghe* was a single-tower building that was reinforced and surrounded by a bastion built probably during the construction of the square (Bafico et al 1985; Bafico 1998; Giardino and Lo Schiavo 2007). The *nuraghe* was in use until the tenth century BCE and was then probably abandoned in a subsequent period, but the village possibly survived, as the society of the whole region (known as Nurra) started to undergo a deep process of transformation.

Recent excavations (De Rosa et al 2017; Rendeli 2018) have unearthed a surprising find: a monumental area, which acted as a market place, created approximately 800 BCE (Fig. 1).

[1] The coordinates were taken by Google Earth on the top of the nuraghe.

✉ M. Rendeli
rendeli@uniss.it

1 Dipartimento di Fisica G. Occhialini, Università degli Studi di Milano Bicocca, Piazza della Scienza 3, 20126 Milano, Italy

2 Istituto Nazionale di Fisica Nucleare-Sez. Milano Bicocca, Piazza della Scienza 3, 20126 Milano, Italy

3 Università degli Studi di Sassari, Piazza Università 21, 07100 Sassari, Italy

4 Ministero della Cultura–Soprintendenza Archeologia, Belle Arti e Paesaggio per le province di Sassari e Nuoro, Piazza Sant'Agostino 2, 07100 Sassari, Italy

5 Laboratori Nazionali del Sud–Istituto Nazionale di Fisica Nucleare, Via Santa Sofia 62, 95123 Catania, Italy

6 Trace Technologies, Via I. Silone 6, 64015 Nereto, TE, Italy

7 Servizio di Chimica, Laboratorio Nazionale del Gran Sasso-Istituto Nazionale di Fisica Nucleare, Via G. Acitelli 22, 67100 Assergi, AQ, Italy

8 LIMS, Laboratorio Nazionale del Gran Sasso-Istituto Nazionale di Fisica Nucleare, Via G. Acitelli 22, 67100 Assergi, AQ, Italy

9 Istituto Nazionale di Fisica Nucleare-Sez. di Cagliari Monserrato, Strada provinciale per Sestu, Km 1, 09042 Monserrato, CA, Italy

10 Centro Universitario Datazioni e Archeometria Milano, Università degli Studi di Milano Bicocca, Piazza della Scienza 1, 20126 Milano, Italy

11 Institut für Geologie, Universität Bern, Baltzerstrasse 3, 3012 Bern, Switzerland

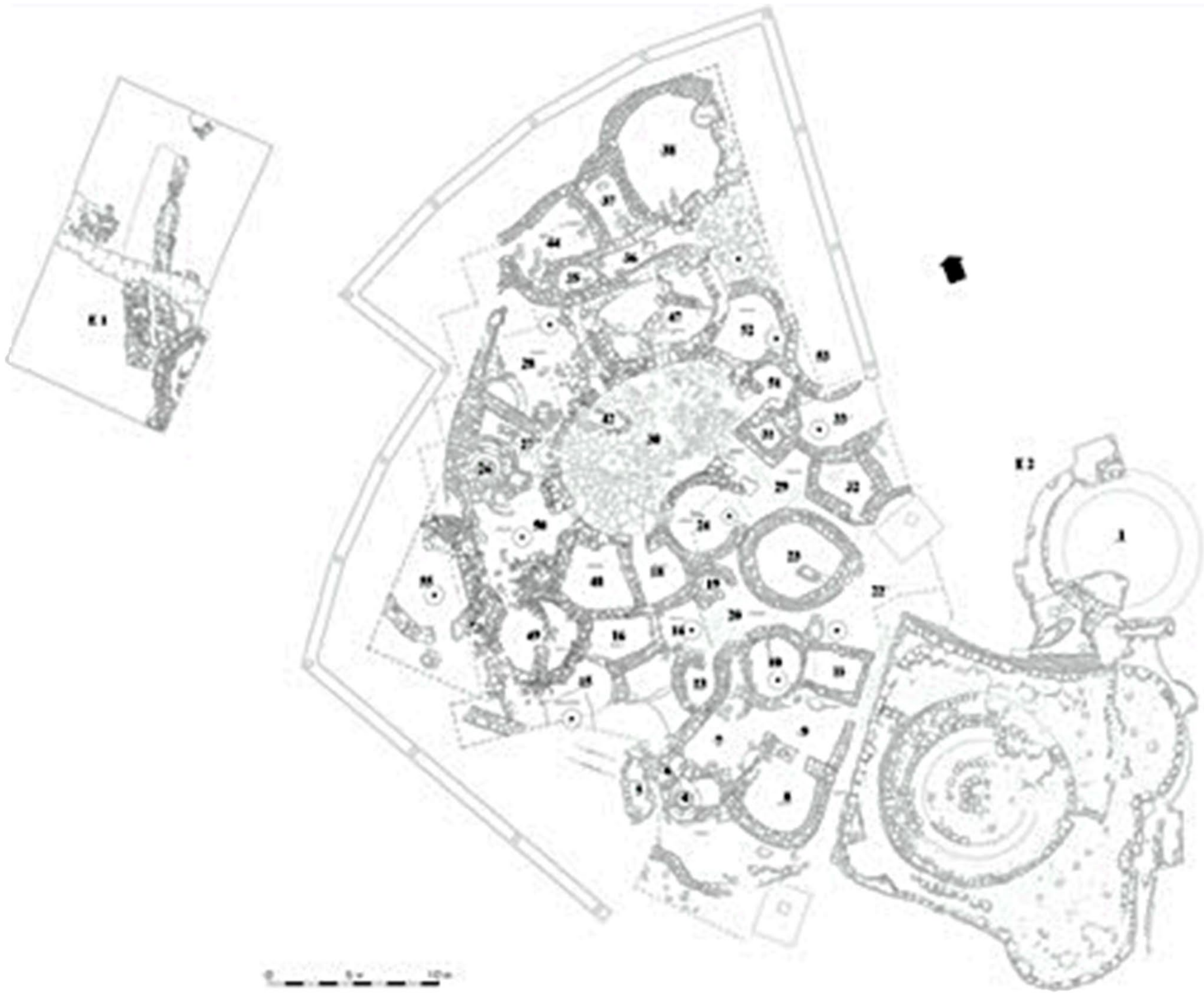


Fig. 1 Plan of the Sant'Imbenia Nuragic complex (Alghero, Sardinia)

Such a market at this early date points to seafaring travel around the Western Mediterranean Sea at the time of settlement by Aegean and Levantine seafarers (Rendeli 2018). The geographical position of Sant'Imbenia makes it a favourable stop on the sea routes in the Western Mediterranean. Marine currents lead westward from NW Sardinia, making it a doorway to the Balearic Islands and S Iberia; moreover, the sheltered natural gulf of Porto Conte lies near the Nurra area, one of the richest areas of Sardinia both for agriculture and sheep breeding and for metals. The floor of the market place was higher than the shops and open areas, and around it one may imagine the presence of shops (A 52, 51, 24, 18, 48); working spaces (A 50, 28); and a bigger room (A 47) in which it is possible to recognize a sort of institutional hall where economic exchanges and treaties could have been stipulated.

Great importance has been given to the "shops". In many of them, some repositories or hoards were found under the floor: two from A 24 that, together with the two found in the nearby A 26, capanna dei ripostigli, amount to more than 140 kg of metal, mainly copper, but also some bronze objects (axes, part of a sword, bracelets).

Among other metal objects, there are many pieces of lead: not slag or ingots but rather clamps for mending pottery known as laminae. These were found all over the area of excavation in the levelling layers or in the preparations of floors (Depalmas et al. 2011: 231–256). Some of these were found whole; some were fragmented.

In A 48 another repository contained more than 1 kg of milk thistle (Silybum marianum) seeds: this is an extraordinary discovery because the seeds were valued as much as precious metals. Pliny the Elder regarding this kind of seed states that the origin of this wild plant can be identified in the Levantine area: the main reason could have been medical use, for the treatment gastric or liver problems which may have affected sailors arriving in the Gulf of Porto Conte (Marino 2014).

As regards the secondary products, of great importance is the collection of more than 200 sherds of amphorae rims, mainly produced at Sant'Imbenia and exported to the Italian peninsula, to N Africa (Utica and Cartage), and S Spain (Huelva, Cadiz, Malaga, La Rebanadilla, Castillo de Doña Blanca) with the Sardinian wine drinking set composed of askoid jugs, neck vases, and possibly cups.

This rich environment was exploited by local societies, which created a network and traded with merchants coming from the Levantine and Aegean areas, from the Italian peninsula, N Africa and S Spain (De Rosa et al 2018; Rendeli 2018).

These conditions likely spurred growing interest in this region among foreign merchants; together with the endogenic transformations occurring in local societies, this caused a critical change in the political organization and in social and economic life. In this phase, craft specializations were developed for the exploitation of both primary and secondary resources. The beginning of the relationship was based on the demand-offer scheme in many fields of local production: primarily as cereals, wine, oil, cheese, meat, metals, leather; secondarily for all the derived products or those useful to increase the exchange: potters, craftsmen, blacksmiths (Giardino and Lo Schiavo 2007; De Rosa et al 2017; Rendeli 2018). These transformations changed the local society, which became specialized and segmented: many of these changes were carried out within the local society, others with the collaboration and co-sharing of foreign specialists and people.

The present investigation endeavours to ascertain the range of commercial traffic during the heyday of the Sant'Imbenia emporium. A very useful tool is the use of lead isotope compositions (PbIC) to infer the provenance area of metal artefacts (Grögler et al 1966; Gale et al 1997; Trincherini et al 2001, 2009; Villa 2016). Especially the PbIC of circum-Mediterranean ore deposits of antiquity has been documented in a number of studies and databases (Stos Gale et al. 1995: Oxalid database; Trincherini-LIMS (to be published); Atzeni et al 2005; Begemann et al 2001).

Description of samples

Eighteen metal samples from Sant'Imbenia were selected for PbIC analyses. The following catalogue briefly reports the nature of each object, its context and possible date based on stratigraphic analysis:

1. A 47, US 832: part of a cubic lead weight from a layer of friable black earth in the NW area of A47 beside the north wall. First half of the eighth century BCE. 1.4 × 1.5 cm; passing hole diam. 0.2 cm in upper part; 0.3 cm in lower part; 11.0 g
2. A 24, US 51: large lead clamp to repair a storage vessel, composed of many laminae: it comes from a layer which obliterates the whole area after the abandonment of the site; it may date to the first half of the sixth century BCE. Big clamp: length 10.0 cm, length 2.0 cm, thickness 0.5 cm: length to the elbow 5.2 cm; after the elbow 2.4 cm, thickness 0.8 cm, max thickness 1.4 cm; nail height 3.6 cm thickness 0.8 cm; head height 2.5 cm, length 1.6 cm; weight 122 g. Big lamina: height 5.8 cm, length 1.7 cm, thickness 1.3 cm, weight 32 g. Small lamina: height 3.4 cm, length 1.5 cm, thickness 0.5 cm, max 0.9 cm, weight 20 g. Total weight 174 g
3. A 24, US 404: lead lamina from the floor in which a hole was created to insert the large storage vessel, a repository for copper slag, axes and part of a sword. Dated around the middle eighth century BCE. Height 2.6 cm, length 1.6 cm, thickness 0.5 cm, weight 20 g
4. A 50, US 111: oval lead plaque missing one extremity from a layer beside the vertical kiln in A50 dated to the seventh century BC. Height 7.5 cm; length 5.0 cm; thickness 0.3 cm; hole height 0.7 cm, length 0.4 cm, weight 77 g
5. A 18, US 434: lead lamina, part of a clamp coming from the preparation layer of a floor; second quarter of the eighth century BCE. Height 3.7 cm, length 1.1 cm, thickness 0.3 cm, max 0.5 cm, weight 10 g
6. A 47, US 52: part of a clamp from a layer of ancient obliteration in A47 after the abandonment of the site, first half of the sixth century BC; height 4.3 cm, length 1.1 cm, thickness 0.2 cm; nail: height 1.4 cm, thickness 0.45 cm; head length 1.4 cm, height 0.8 cm, thickness of the head 0.2 cm, weight 9 g
7. A 48, US 829: lead lamina (?) with a ribbon section coming from the preparation layer of a floor in A48, second quarter of the eighth century BC. Height 3.6 cm, length 1.4 cm, thickness 0.5 cm, weight 11 g
8. A 48, US 396: cubic lead weight from a layer of fill of a large fossa in the most recent floor of A48, near the rim of the large storage vessel used as repository for milk whistle seeds; mid eighth century BCE. 1.9 × 1.8 × 1.5 cm^3, weight 47 g
9. A 52, US 675: part of lead lamina from the preparation layer of a floor US 505; end of the eighth–first half of the seventh century BCE. Height 2.7 cm, length 1.2 cm, thickness 0.6 cm, weight 10 g
10. A 49, US 1100: big lead clamp created to restore at least 6 sherds of a large storage vessel, from a floor layer of A49: dated to between the eighth and seventh centuries BCE. Length 1.4 cm, thickness 0.4 cm; weight with the sherds of pottery 448 g

Table 1 List showing analysed samples, objects, measured isotope ratios and analytical technique used

No	Sample	Artefact	$^{207}Pb/^{206}Pb$	*uncertainty ± 2σ*	$^{208}Pb/^{206}Pb$	*uncertainty ± 2σ*	$^{206}Pb/^{204}Pb$	*uncertainty ± 2σ*	Instrument
1	SI_2013_A47_U832	Cubic weight	0.87397	*0.00003*	2.1223	*0.00011*	17.903	*0.002*	MC-ICP-MS
2	SI_2010_A24_US51	Agraffe	0.87390	*0.00003*	2.1223	*0.00012*	17.902	*0.002*	MC-ICP-MS
3	A24 US404	Lamina	0.87336	*0.00004*	2.1183	*0.00014*	17.863	*0.007*	TIMS
4	A50 US111	Plaque	0.87230	*0.00006*	2.1175	*0.00017*	17.898	*0.007*	TIMS
5	SI_2012_A18_US434	Lamina	0.87222	*0.00004*	2.1203	*0.00013*	17.937	*0.002*	MC-ICP-MS
6	SI_2009_A47_US52	Clamp	0.86036	*0.00002*	2.1069	*0.00008*	18.203	*0.002*	MC-ICP-MS
7	SI_2013_A48_US829	Lamina (?)	0.86014	*0.00003*	2.1067	*0.00011*	18.208	*0.002*	MC-ICP-MS
8	A48 US396	Cubic weight	0.86007	*0.00003*	2,1064	*0,00,017*	18.207	*0.002*	MC-ICP-MS
8bis	A48 US396	Cubic weight ext	0.85999	*0.00002*	2.1060	*0.00007*	18.204	*0.002*	MC-ICP-MS
9	A52 US675	Lamina	0.85815	*0.00005*	2.1028	*0.00012*	18.197	*0.007*	TIMS
10	A49 US1100	Clamp	0.85785	*0.00005*	2.1052	*0.00019*	18.278	*0.007*	TIMS
11	A44 US798	Lamina	0.85741	*0.00005*	2.1007	*0.00008*	18.193	*0.004*	TIMS
12	A52 US505	Lamina	0.85580	*0.00005*	2.1028	*0.00013*	18.261	*0.007*	TIMS
13	A47 US135	Lamina	0.85529	*0.00005*	2.0921	*0.00010*	18.307	*0.007*	TIMS
14	SI_2011_A47_US175	Object	0.85455	*0.00002*	2,1003	*0.00010*	18.332	*0.002*	MC-ICP-MS
15	SI_2013_A16_US923	Lamina	0.85448	*0.00003*	2.1003	*0.00015*	18.322	*0.002*	MC-ICP-MS
16	SI_2015_A29_US1372	Lamina	0.85448	*0.00002*	2.1003	*0.00011*	18.335	*0.002*	MC-ICP-MS
17	E1 US1246	Clamp	0.85383	*0.00004*	2.0962	*0.00012*	18.298	*0.007*	TIMS
18	SI_2008_US1_SO	Clamp	0.83942	*0.00004*	2.0834	*0.00015*	18.663	*0.002*	MC-ICP-MS

11. A 44, US 798: part of a lead lamina from a fill layer of a cut made in modern times. Height 2.4 cm, length 2.4 cm, thickness 0.4 cm, weight 20 g
12. A 52, US 505: small part of a lead lamina from a floor of A52; end of the eighth–mid seventh centuries BCE. Height 2.3 cm, length 1.0 cm, thickness 0.4 cm, weight 6 g
13. A 47, US 135: lead object with an ovoid profile, from a floor layer in A47; second half of the eighth century BCE. Height 3.7 cm, length 1.8 cm, thickness 1.3 cm, weight 42 g
14. A 47, US 175: lead object from a floor layer in A47, dated to around middle eighth century BCE: height max 4.2 cm, length on thicker part 2.4 cm, otherwise 1.9 cm; thickness 0.8–0.4 cm, weight 28 g
15. A16, US 923: lead element possibly decorating a wooden box, from the preparation layer of a floor in A16; dated to between mid eighth and mid sixth centuries BCE. Height 2.8, length 1.1 cm, thickness from 2.4 cm to 0.4 cm, weight 12 g
16. A 29, US 1372: small lead lamina, part of a clamp, found between the blocks making up the floor of the Piazzetta (A29), dated to between the mid eighth and the mid seventh centuries BCE. Height 1.85 cm, length 0.8 cm, thickness 0.4 cm, weight 3 g
17. S expansion of the area E1, US 1246 lead clamp found in a layer of abandonment of the area during the first half of the sixth century BCE. Height 4.0 cm, length 1.4 cm, height 1.2 cm; thickness of the laminae 0.2 cm, thickness of the nails 0.5 cm, weight 14 g
18. 2008, US 1: SW area, part of a lead clamp from the humus layer in the SW area of the excavation. No date available. Height 4.9 cm, length 0.9, thickness 0.4 cm, weight 15 g

Lead isotope analyses were performed partly by thermal ionization mass spectrometry (TIMS) by the Laboratori Nazionali del Gran Sasso of the Istituto Nazionale di Fisica Nucleare (LNGS), Assergi, Italy, and partly by multicollector ion-source mass spectrometry (MC-ICP-MS) by the Centro Universitario Datazioni e Archeometria (CUDAM), University of Milano Bicocca, Italy. The analytical procedures employed are described in Trincherini et al 1983; 2001 and Villa 2009, respectively.

Results are shown in Table 1.

Geographical provenance

The PbIC measurements display a great variety, which extends far beyond the PbIC range of the known ore showings in Nurra, the immediate hinterland of the site.

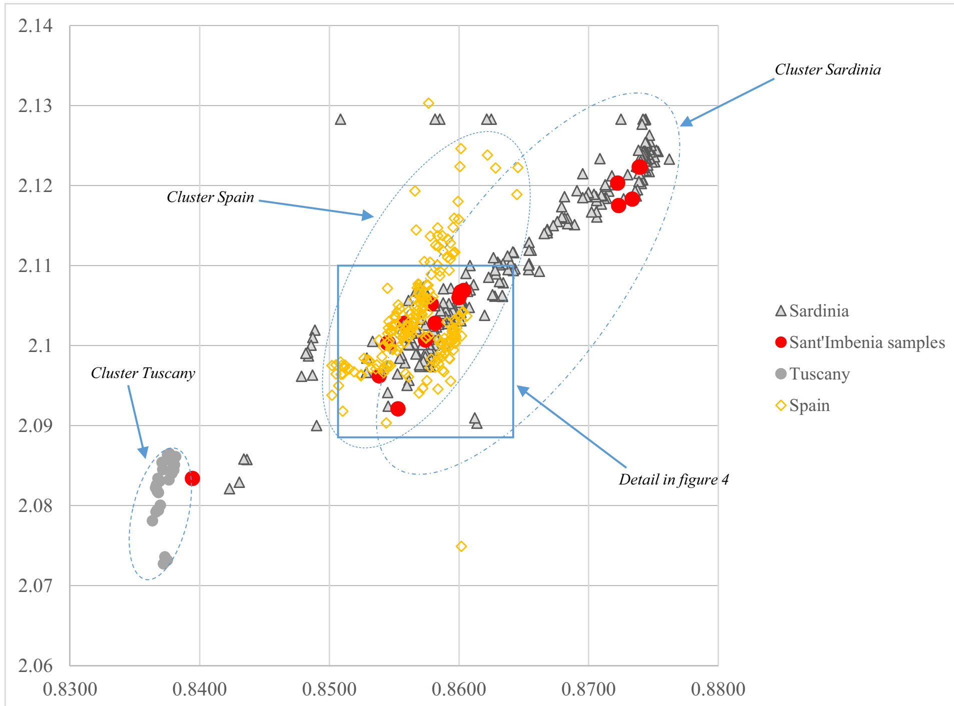


Fig. 2 Scatter plot of lead isotope compositions ($^{208}Pb/^{206}Pb$ vs $^{207}Pb/^{206}Pb$) of the minerary areas and 18 samples from Sant'Imbenia (red circles)

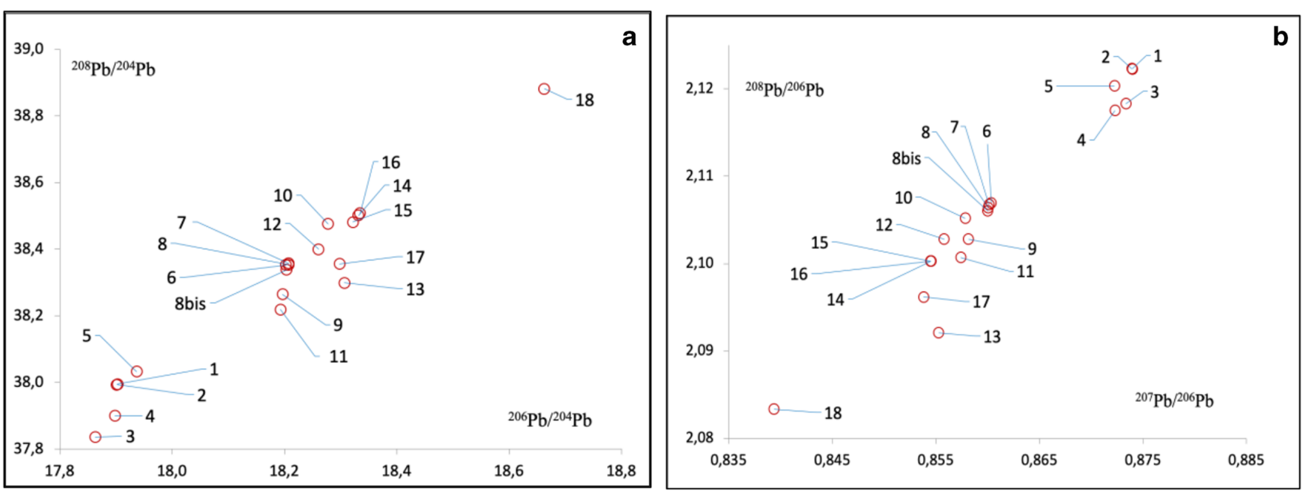


Fig. 3 a–b Common-denominator diagrams (^{204}Pb and ^{206}Pb) displaying the Sant'Imbenia samples

Taking into account the geographical location of Sant'Imbenia, the relation and compatibility of the metal objects with possible sources were explored: firstly the ore areas in Sardinia, then in other Mediterranean areas. Figure 2 shows the distribution of the 18 samples among the mining regions cited in the archives used in this article.

One extremely important point to always bear in mind is that all of these databases, despite their large collection of samples, are by definition incomplete. First of all, present-day outcrops are not exhaustively charted. Metre-sized outcrops, which could have supplied a few tons of ore, may well be hidden below vegetation or modern buildings or in presently inaccessible areas. Secondly, ore showings evident in the Nuragic era may have been exhausted over the centuries and hence no longer appear on maps. Thirdly, it is a well-known fact that the PbIC of minerals in a single mine are variable at the cm scale and at the 10 m scale (e.g. Kang et al 2020, and references therein); unless one analyses the entire mineralized volume of a mine, it is impossible to eliminate the doubt that one mineral that was not sampled could be isotopically

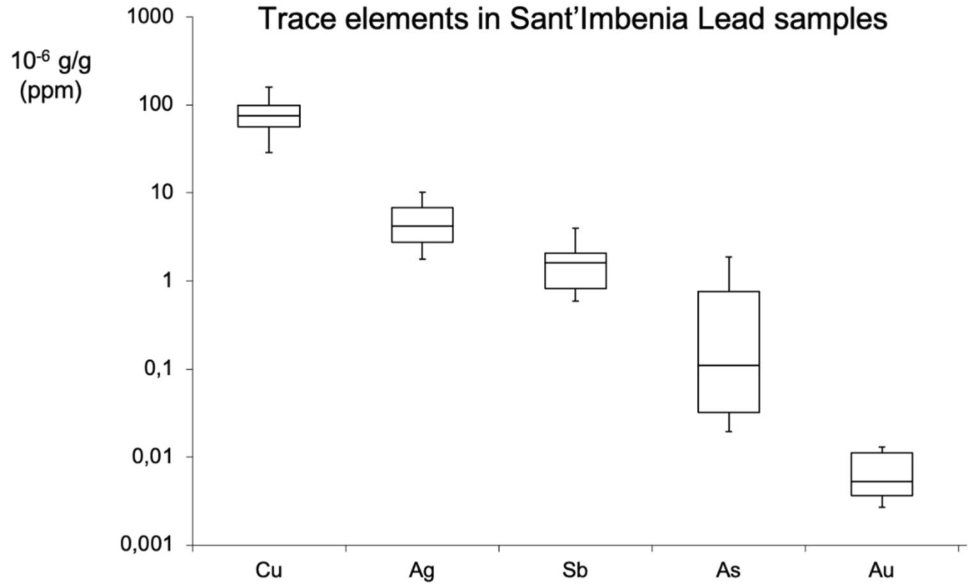


Fig. 4 Boxplot showing trace element distributions of Sant'Imbenia lead samples measured with neutron activation analysis (for detail see Romanò 2016)

different from those that were. Another source of ambiguity is the frequent practice of recycling metals and mixing ore batches from different ore deposits. In the common-denominator diagrams displaying data, all "binary" mixtures (mixtures between N end-members lie in a polygon with N vertices) are manifested as linear segments connecting the two mixing end-members; mixtures always lie between the pure end-members. Figure 3a–b show the common-denominator diagrams for the isotopes 204 and 206.

Lead can also be considered a clue for the extraction of silver, separated by *cupellation* from galena, richly found in Sardinia (Pearce 2018). One aspect that has not yet be clearly settled is if cupellation was a widespread practice at the time of the Sant'Imbenia emporium. According to Perelló and Llull (2019), the invention of cupellation is ascribed to the Phoenician colonists after the eighth and seventh centuries. Thus, the observation that the lead objects in Sant'Imbenia have low silver concentrations (see Fig. 4 and Table 3 in Appendix) can point to an earlier invention of cupellation than in the Balearic Islands, but can also be due to the mining of Ag-poor galena, as is observed in present-day ore deposits (e.g. Kang et al 2020).

Bearing in mind these caveats, it is possible to reliably assign a SW Sardinian provenance to five samples shown in Table 1 (those falling in the range $0.87176 \leq {}^{207}Pb/{}^{206}Pb \leq 0.8742$, $2.1187 \leq {}^{208}Pb/{}^{206}Pb \leq 2.1244$, typical of Early Paleozoic mineralizations). These PbIC ranges perfectly overlap with the mines of Buggerru, San Giovanni Bindua, Domusnovas and Carreras, all in the Sulcis-Iglesiente-Fluminese areas in the SW Sardinia. From our Sardinia database, 28 samples with isotopic ratios ${}^{207}Pb/{}^{206}Pb$ and ${}^{208}Pb/{}^{206}Pb$ close to the five samples were selected within the following ranges (see Table 4 in Appendix). This PbIC signature cannot be explained by anything other than a direct derivation of these five metal objects from the above mines. If they were to be interpreted as recycling-cum-mixture, one would have to hypothesize an end-member lying further towards higher ${}^{207}Pb/{}^{206}Pb$ and ${}^{208}Pb/{}^{206}Pb$ ratios, which is however not found in the Western Mediterranean (Fig. 5).

The match with the two mines in the Iglesiente district, Buggerru and San Giovanni Bindua, is almost total: despite being about 30 km apart, the two mines have exploiting veins with very similar isotopic ratios (see Table 5 in Appendix). While samples 3 and 4 can be matched with two mines in the Iglesiente district (Domusnovas and Carreras), sample 5 does not fit any isotopic ratio even if it is clearly attributable to the Sulcis area.

The situation for the 13 samples (6–17) lying in the centre of Fig. 2 is more complex: in this part of the diagram, it is possible to observe the overlap of the PbIC of some Sardinian and Iberian mines.

Figure 6 shows a detail of the selected area in Fig. 2: among the twelve samples, the top four on the right are compatible with Sardinian ores: the dotted line delimits an area in which the Iberian mines become predominant.

Four of the samples, 6 to 8 bis, falling in the range $0.8600 \leq {}^{207}Pb/{}^{206}Pb \leq 0.8604$, $2.1060 \leq {}^{208}Pb/{}^{206}Pb \leq 2.1069$, typical of Late Paleozoic mineralization, overlap with the Montevecchio mine, in the Arburese area (W Sardinia).

In Fig. 7 the total overlap with the Montevecchio area (Arbus) and a partial overlap with a few samples from the Rio Tinto

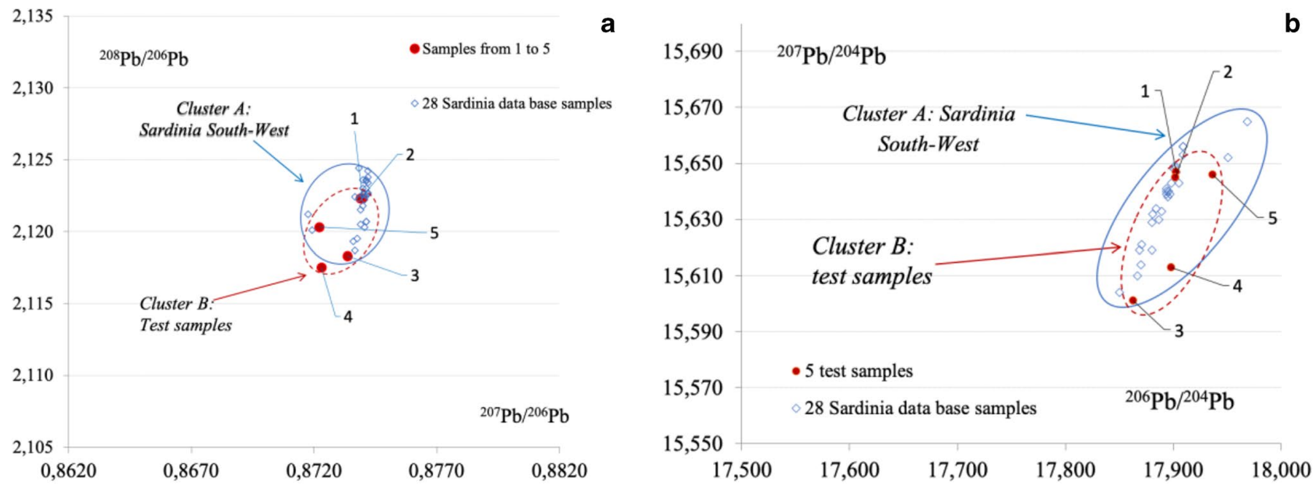


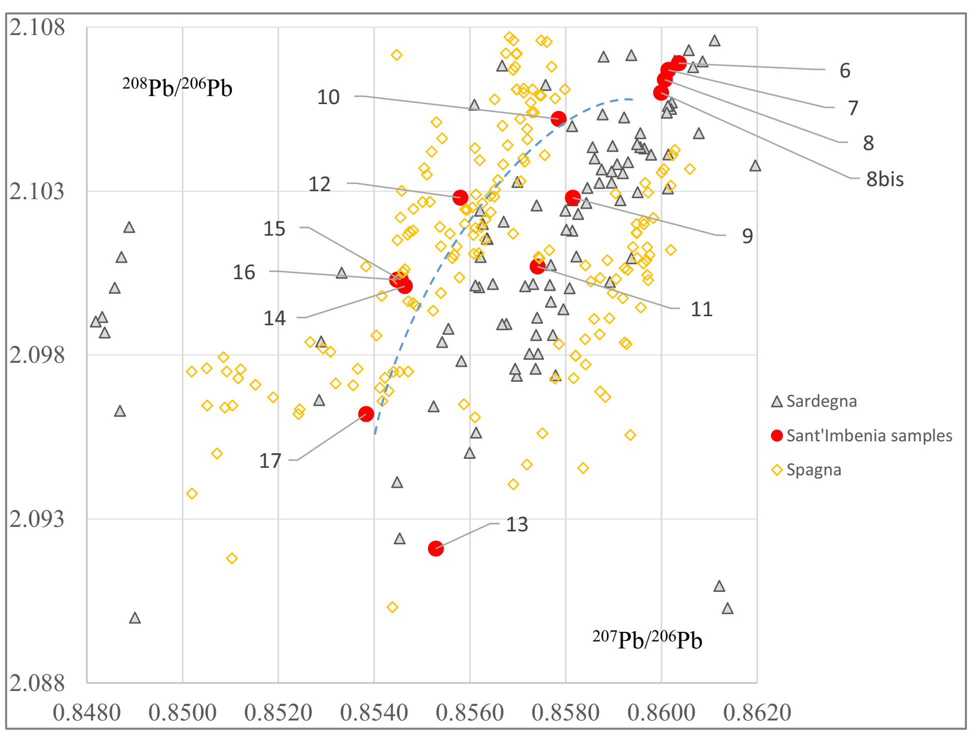
Fig. 5 a–b Distribution of 5 samples from S. Imbenia (dark circles) and 28 values (light diamonds) from Sardinian mine districts of the Fluminese-Iglesiente areas isotopically nearer to the first ones. Samples from 1 to 5 as listed in Table 1

district (Huelva, S Spain) can be observed at the very end of the cluster (see Table 6 in Appendix).

The remaining samples (9–13 of Table 1) present PbIC values ($0.8553 \le {}^{207}Pb/{}^{206}Pb \le 0.8582$) that overlap with several Late Paleozoic–Early Triassic mineralizations in the circum-Mediterranean region. These include S Iberia but also small and very small ore showings in Sardinia (Argentie-ra) Gale and Stos Gale 1987; 1988; Barbagia-Nuorese: Stos Gale et al. 1995; Gerrei-Sarrabus: Stos Gale et al. 1995) that cannot be part of the previous cluster (Fig. 9).

It is not vital for the present discussion to determine all possible minor ore sources, as recycling and mixing of metal batches of disparate origins needs to be taken into account (see also "Discussion" below).

Fig. 6 Detail of Fig. 2, Iberian and Sardinian ores



Of notable interest is the cubic weighing standard (samples 8, 8bis). Its mass, ca. 47 g, relates to both Aegean and Levantine weight systems (see *infra* in "Archaeological Conclusions"). We have analysed both the discoloured surface and an interior piece, as alteration patinas and unaltered interiors could be a priori isotopically different. Only after the measurement we were able to determine that the mass balance of the alteration produced a negligible isotopic bias. The analyses of its weathering crust and of the unaltered interior coincide, indicating that the measured PbIC was not perturbed during the last 2800 years. The purpose of this standard was certainly not the weighing of agricultural products (which would have been traded at least in the kg range) and could refer instead to the weighing of small amounts of products such as herbs for medical use and/or spices, milk thistle and fenugreek, which was found in a repository (A48) and today it is extremely abundant in North Western Sardinia (Marino 2014: 49–58) (Fig. 8).

Samples 9–13 have shown compatibilities coherent with Sardinian districts (see Tables 7–10 in Appendix).

Samples 9 and 11 have their compatibilities with the Sulcis District because of the isotopic ratio 207Pb/206Pb = 0.85624, which is the highest in the area (see Table 7 in Appendix). Different geographic provenances have to be found for the samples 12 and 13. Figure 9 highlights the compatibility between samples 9 and 11 (two laminae) and some mines in the *Sulcis* district.

The three samples (9–11) should be analysed in relation with other mine districts and it is possible to observe that: for sample 10, a different provenance can be assumed and different mines have similar lead isotopic composition. L'Argentiera (Sassari) is one of them but there is not a sufficient homogeneity of the isotopic ratio values to assign the sample with certainty to this area. Another mine in SE Sardinia, Pranu 'e Sanguini, in the Gerrei-Sarrabus region, offers a similar but not overlapping isotopic composition, as can be seen in Fig. 9. The mean of the other samples is notably different (Es. $^{207}Pb/^{206}Pb = 0.85624 \pm 0.0009$): for this reason, the compatibility cannot be deemed sufficient (see Tables 8 and 10 in Appendix).

The remaining samples (12 and 13) have PbIC signatures typical of Cenozoic mineralization. The most prominent Cenozoic ores are found in the Catalan Coastal Ranges District near Tarragona. This district is characterized by many large and small mines with Pb isotopic ratios $0.8548 \leq {}^{207}Pb/^{206}Pb \leq 0.8565$, $2.0994 \leq {}^{208}Pb/^{206}Pb \leq 2.1027$ (see Table 9 in Appendix). However, small and poorly charted showings in NW Sardinia (e.g. Calabona and Bonu Ighinu: Begemann et al 2001) also should be considered possible sources. It is very important to note that the question of provenance must never be asked as "which mining district has an average isotopic composition closest to the investigated sample", as the correct question is instead "which

Fig. 7 Detail of Rio Tinto and Arburese clusters

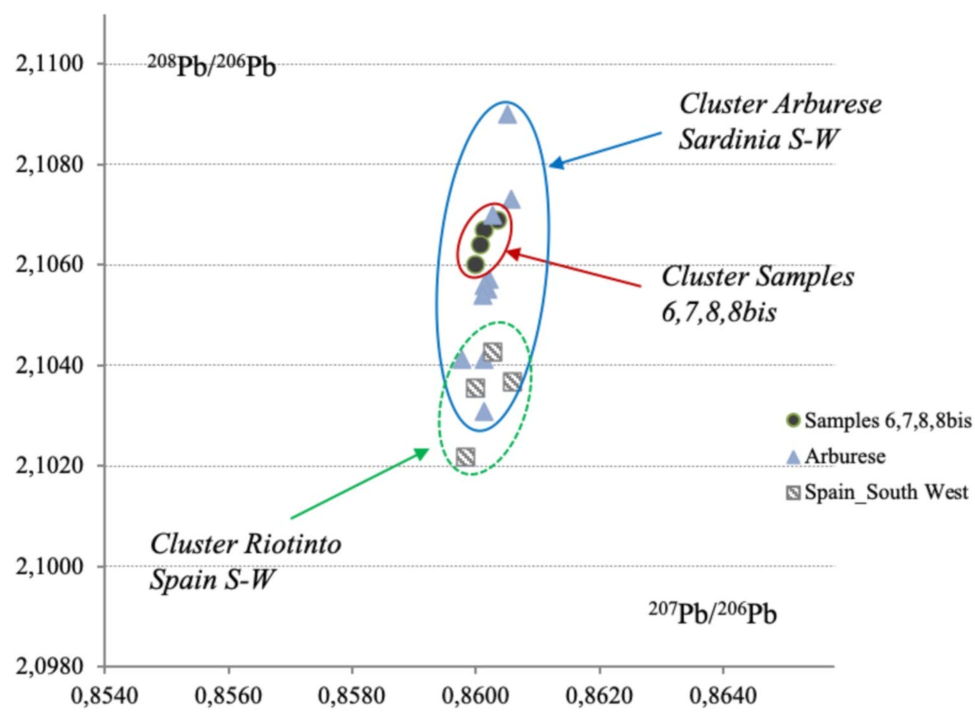


Fig. 8 The weight from A48, US 396 (photo M. Rendeli)

mining district has at least one data-point that coincides with the investigated sample". Thus, one single small outcrop from W Sardinia might be the true source of one object, even if hundreds of ores from all over the world also have the same PbIC.

Samples 12 and 13 lie outside the database of isotopic ratios collected for the Sardinian mines: Fig. 9 shows values on which the clusters are built (see Tables 9–11 in Appendix), distinguished for different districts in Sardinia. Since Pb isotope analyses are not an unambiguous proof of provenance but an indication of compatibility, it is very important to avoid proposing a Sardinian origin basing on purely isotopic grounds, but to include the independent, non-isotopic, archaeometric/archaeological context.

Using the same criteria, other Mediterranean mines are taken into consideration, with appropriate isotopic ratios in order to research compatibilities for samples 12 and 13, adding also sample 10 to verify its origin.

From our research emerges that the Catalan Coastal Ranges District may offer three interesting areas in the inland of Tarragona (from NE to SW): Ulldemolins, Priorat and Tarragona (see Table 9 in Appendix).

This district is characterized by a series of small mines with isotopic ratios: $0.85477 \leq 207Pb/206Pb \leq 0.85646$

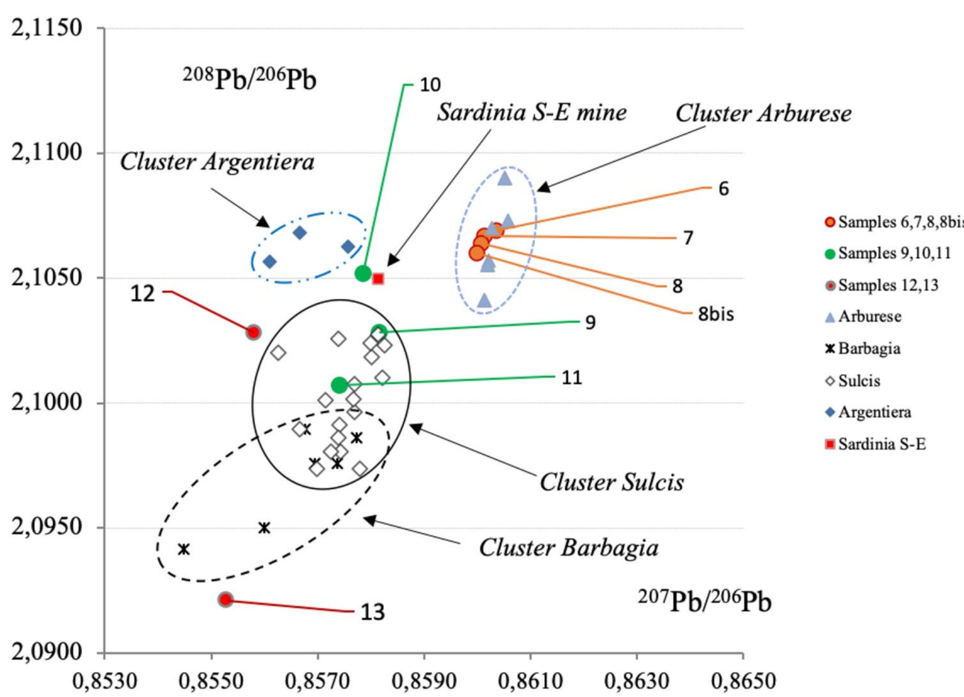


Fig. 9 Representation of different Sardinian clusters and possible overlap with Sant'Imbenia

Fig. 10 Overlap of samples 10 and 12 with Sierra Morena and Catalan Coastal Ranges

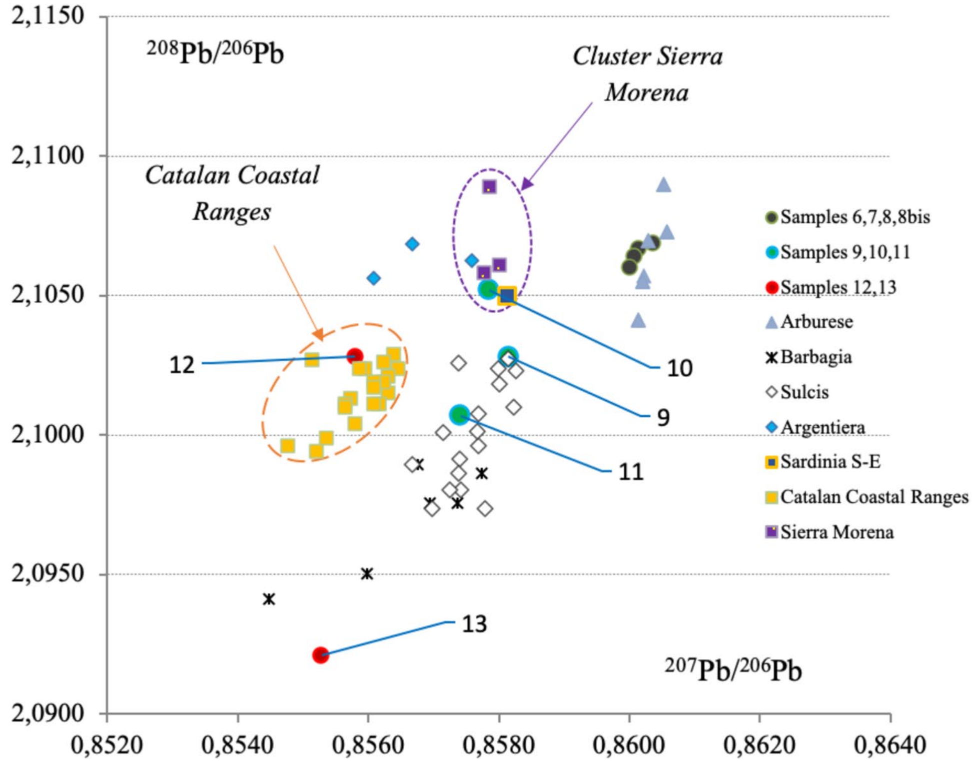


Fig. 11 Overlap of samples 13, 14, 15, 16 and 17 with Funatana Raminosa, CCR2 and Spain S-E clusters

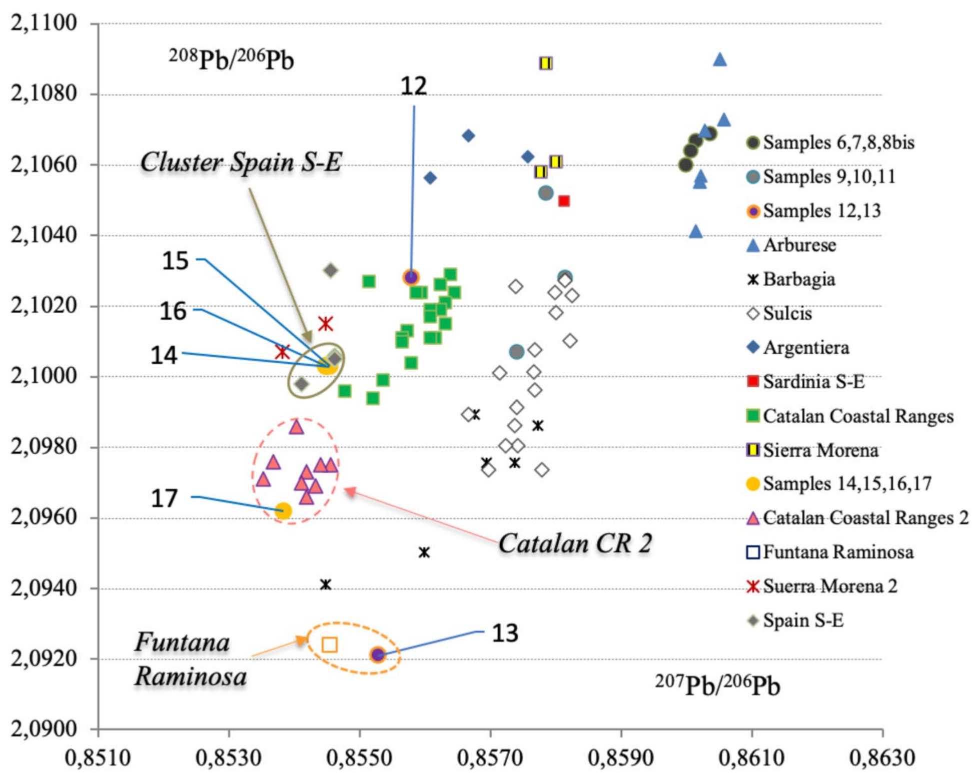


Table 2 Possible compatibilities for the provenance of lead from the excavations of Sant'Imbenia (Porto Conte, Alghero, Sardinia)

No	Sample	Object	Origin		
			Region	Mine districts	Mine site
1	SI_2013_A47_U832	Cubic weight	Sardinia	Sulcis-Iglesiente	San Giovanni
2	SI_2010_A24_US51	Clamp	Sardinia	Sulcis-Iglesiente	Buggerru
3	A24 US404	Lamina	Sardinia	Iglesiente-Domusnovas	Marganai
4	A50 US111	Plaque	Sardinia	Sulcis-Iglesiente	Carreras
5	SI_2012_A18_US434	Lamina	Sardinia	Sulcis-Iglesiente	-
6	SI_2009_A47_US52	Clamp	Sardinia	Arburese	Montevecchio
7	SI_2013_A48_US829	Lamina	Sardinia	Arburese	Montevecchio
8	A48 US396	Cubic weight	Sardinia	Arburese	Montevecchio
8bis	A48 US396	Cubic weight ext	Sardinia	Arburese	Montevecchio
9	A52 US675	Lamina	Sardinia	Sulcis	Sulcis, Rosas Narcao (SU)
10	A49 US1100	Clamp	Sardinia /(Spain)	Sardinia S-E /Sassarese	Sarrabus Gerrei / Argentiera
11	A44 US798	Lamina	Sardinia	Sulcis/Barbagia	Funtana Raminosa
12	A52 US505	Lamina	Spain	Catalan Coastal Ranges	-
13	A47 US135	Lamina	Sardinia	*Barbagia*	*Funtana Raminosa*
14	SI_2011_A47_US175	Object	Spain	Almerìa	Sierra Alhamilla
15	SI_2013_A16_US923	Lamina	Spain	Almerìa	Sierra Alhamilla
16	SI_2015_A29_US1372	Lamina	Spain	Almerìa	Sierra Alhamilla
17	E1 US1246	Clamp	Spain	Catalan Coastal Ranges	-
18	SI_2008_US1_SO	Clamp	Spain Italy	Castellòn/Cartagena-Mazarron Tuscany	-

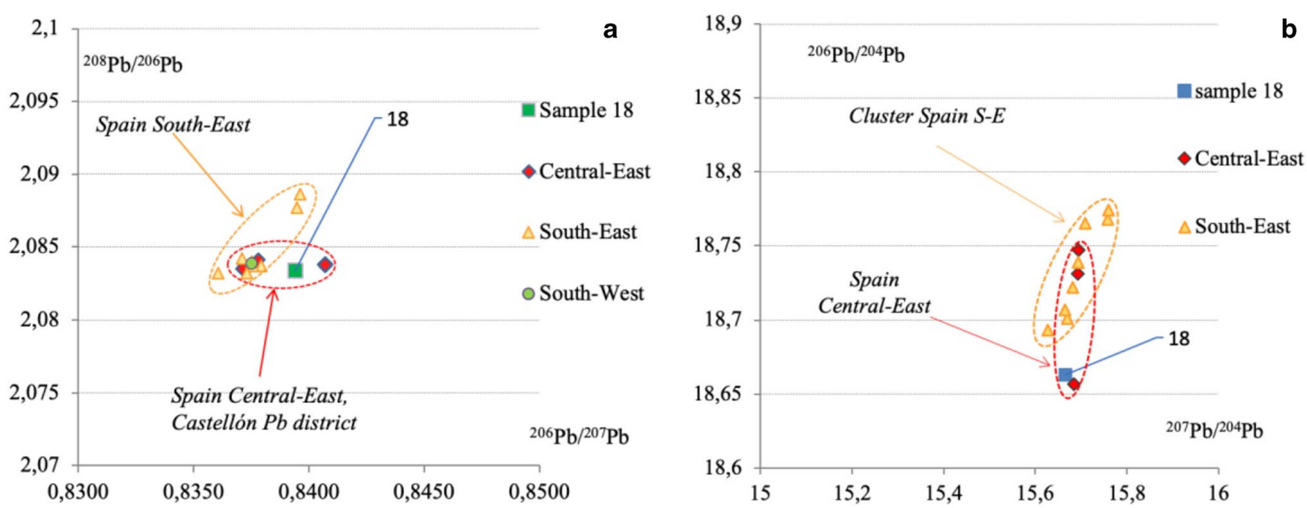


Fig. 12 a–b Overlap of sample 18 with Central-East Spain cluster created with the isotopic ratios j/206 and j/204

and 2.0994 ≤ 208Pb/206Pb ≤ 2.1027. We can add some mines from the Sierra Morena (see Table 10 in the Appendix) and, in Sardinia, the Barbagia District the mine of Funtana Raminosa (see Table 11 in the Appendix).

Some of the samples are from the Sierra Morena (Spain) mines, and these can be placed near our sample 10 creating a small cluster, which includes other mines from N and S Sardinia that have already been discussed. Even with these data, the attribution of sample 10 remains quite dubious: the Sardinia reference is precise but weak for its unicity, the samples from Sierra Morena may represent its origin but without complete certainty. On the contrary, for sample 12, its inclusion in a cluster made up of many samples suggests the high probability that the mineral is from the mines of the

Catalan Coastal Ranges. Among the mines of this district, the Raimunda mine shows the best compatibility. Sample 13 remains in isolation in Fig. 10 with no contribution to determine its geographic origin: its isotopic signature, if placed in the overall distribution (Fig. 2), finds some marginally compatible isolate mines.

Samples 14 to 17, with isotopic ratios $0.85383 \leq 207Pb/206Pb \leq 0.85455$ and $2.0962 \leq 208Pb/206Pb \leq 2.1003$, constitute a homogenous group: samples 14, 15 and 16 are almost identical while the fourth, 17, differs only slightly. Figure 11 shows the mines with compatibilities the value of our samples, mainly from the Western Mediterranean basin (see Table 12 in Appendix).

Samples 14, 15 and 16 have almost identical isotopic values and in Fig. 11 overlap in one circle (orange in the SE Spanish cluster): this cluster is composed of the minerals from the mines of SE Spain, the district of Almeria-Sierra Alhamilla in particular, which assure a complete compatibility between the isotopic ratios of our objects and those coming from these mines.

As regards sample 17, despite the apparent similarity of its isotopic ratios with those of the previous ones, it has a different origin mostly due to the isotopic ratio 208Pb/206Pb. In Fig. 11, sample 17 lies in a lower area and forms a distinct cluster with some minerals coming from different mines of the district of the Catalan Coastal Ranges.

The last sample (18), with an isotopic ratio 207Pb/206Pb that is much lower in comparison with the others, differs from the whole group.

Better compatibility is offered by a mineral extracted in the district of Castellòn, Plana Alta, which lies on the eastern coast of central Spain (see Table 13 in Appendix): it must be said that in the same district all the mines have different isotopic ratios, closer to those found in the southern area of Cartagena-Mazarròn. In Fig. 12a–b, the set of points to the left of sample 18 represents established mine districts on the E coast, from the Valencian area of the Andalucia. Figure 12b, created with the isotopic ratios j/204, also offers the same interpretation.

Table 2 summarizes the results of the possible compatibilities for the provenance of lead of all the objects reported in Table 1, which are from the excavations of Sant'Imbenia (Porto Conte, Alghero, Sardinia). For all of them, apart from sample 10, the regional origin is certain, the mine district or the mine itself is not defined for all the samples, but their geographic provenance is identified.

Finally, the provenance of sample 18 is especially intriguing, as its PbIC falls at the intersection of the field defined by ores from Etruria (Villa and Giardino 2019) with those from the Catalan Coastal Range (see Fig. 2). No corresponding Sardinian ore has yet been reported and this suggests that in either case the arrival of this object in Sardinia involved maritime trade. Mixing is out of the question, as the ores from Etruria have an extreme PbIC, unmatched by other circum-Mediterranean mining regions, and therefore might qualify as end-members, but not as products, of metal mixing.

Discussion

Notwithstanding all the doubts that surround the assignment of provenance on an individual basis, we can draw some robust and some tentative conclusions regarding the extension of the trade network of Sant'Imbenia.

The circulation of lead is also important because it testifies, indirectly, the organization of local communities in those districts: it opens a new picture on the relations among different areas of the island, all under control of local communities, whose political and economic organization is not known and has to be analysed and understood. Lead is clearly not a precious metal, but its economic importance stems precisely from its low cost: in contrast to gold, it can be used to repair broken ceramics, or to produce low-cost jewellery (e.g. Balassone et al 2002). Circulating lead quantities are higher than in previous periods and the communities should have a different organization, a network on which the vitality testifies a real change, their participation to an internal as well as to international trade and strong relation existing at a regional scale among different political and economic structures. It means also organization of a *chaîne operatoire* that starts from the mines and finishes to the objects and their circulation. The control of the mines in this long period (ninth to the middle sixth centuries BC) should have been in the hand of the local communities, which may have been changed their organization with the aim of responding to all the requests.

The first unexpected, but very robust result is that a substantial proportion of the analysed metal objects derives from the SW Sardinia (Sulcis, Iglesiente and Arburese). Travelling this distance for protohistoric sailors was long and dangerous; overland transport was likely even more arduous. Sant'Imbenia thus was not just a marketplace for goods from the immediate hinterland. A second robust result is that at least one object is incompatible with any Sardinian mining district and thus must have been imported by sea, in particular from Iberia (or perhaps from Etruria, see Fig. 2, Villa and Giardino 2019).

One probable (although not rigorously demonstrated) result is that the coastal ranges of Iberia (Rio Tinto, Almería, Tarragona) are very likely to be the sources for a substantial proportion of the metal objects, even if other, intra-Sardinian sources (Argentiera, Barbagia) are both archeologically and isotopically possible. Furthermore, metal recycling/mixing cannot be excluded.

It is important to bear in mind that, as mentioned above, some individual ore sources may be missing from the databases. Furthermore, any object could be the result of two common metallurgical practices: smelting of ore from different sources and resmelting of recycled objects. In both cases the origin is destined to remain ambiguous.

Archaeological conclusions

The analysis and the results stemming from the isotopic ratios of the objects from Sant'Imbenia in comparison with Sardinian and Mediterranean mining districts or sites provide us with important material to determine the origin and circulation of lead from the ninth to the middle sixth century BCE (Giardino and Lo Schiavo 2007).

The centrality of the site in the Iron age is confirmed by the huge amount of copper slags found in four repositories for some 140 kg: the slags found in two repositories of A23 were analysed by C. Giardino e F. Lo Schiavo together with the one found at Nuraghe Flumenelongu: isotopic measures on lead found in copper show that the provenance of the copper could be diverse (Greece, Cyprus, Tuscany) but part of it could come also from Calabona, nearby Alghero, 20 km south from Sant'Imbenia (Giardino and Pinarelli 2007: 99–109). The mine of Calabona was known in antiquity also for the copper extracted here and exported in Rome to realize the bronze Lupa Capitolina, a discussed masterpiece of the Etrusco-Roman art of the end of the sixth–beginning of the fifth centuries BC (Gale et al 2005: 131–137): these data, together with the pottery finds, show the centrality of the Alghero in the first half of the first millennium BC and in it the role of Sant'Imbenia was central for trade and commerce (Gale et al 2005: 138–139; Rendeli 2018).

Far from the archaeology of repositories or hoards, of slags and ingots, these samples may add new data and *tesserae* to realize a more complete mosaic of the relations between north-western Sardinia, other districts of the island and the Mediterranean area: they are all fragments taken from small objects belonging to the same collection, mainly clamps but also a couple of weights, which may have had a wide circulation in the Mediterranean area (Giardino 1992: 304–316; 2010: 161–177). For all the objects analysed, it is possible to affirm that they have ended their "social life and circulation" at Sant'Imbenia but we cannot define how long these were. Being a market place it would not be surprising if it were to turn out that the lead used came from different provenances, both from Sardinia and other Mediterranean areas.

The lead ratios confirm the trend seen in other classes of material, e.g. pottery (De Rosa 2017) and amphorae (De Rosa and Garau 2016; De Rosa et al 2018): that of a wide interconnection with other districts of the island and other countries in the Central-Western Mediterranean. The meagre quantities of metal in question do not allow the construction of mercantile relations, such as could be the case for the copper with its four repositories (130 kg), but nevertheless they testify that at Sant'Imbenia there was a circulation of lead of different origin, from Sardinia and overseas (most probably Spain, possibly Etruria).

It is not a surprise that the cubic lead weight with a mark of value or a letter (ᶜ*ayin*), found in A 48 in a layer dating to the first half of the eighth century BCE, has isotope ratios which indicates its origin from Montevecchio in the Arburense area (a cubic lead weight with the same mark from Cerro del Villar in an eighth–seventh c. BCE context weighs 14.187 g: Aubet 2002: 32). Its weight of 47 g makes it four times the Microasiatic shekel (11.75 g), five times the Syrian shekel of the Bronze age (9.4 g), six times the shekel of Karkemish (7.83 g), and seven times the Aegean unit (6.5–6.8 g). The multiplicity of ponderal relations (Zaccagnini 1991; Alberti et al 2006: 1–2; Ruiz-Gálvez 2003: 153–155; Lo Schiavo 2006: 367–379), all related to the Eastern and Central Mediterranean, while dissuading us from attributing the weight to any one system, suggests also that this artefact could have been used to "translate" between different ponderal unit systems. At the same time, it encourages the interpretation of Sant'Imbenia as an important "port of trade" and "gateway area" of NW Sardinia with other areas of the Mediterranean.

Many districts are involved all over Sardinia: Sulcis, Iglesiente, Fluminese, Arburese, Buggerru, Nuorese and perhaps also Nurra (Valera and Valera 2005: 35–42; Valera et al 2005: 43–88; Atzeni et al 2005: 160–172). Enlarging the picture, compatibilities between the Sant'Imbenia samples and some Spanish districts have been observed: the Catalan Coastal Ranges, the mine district in the hinterland of Almeria (Sierra Alhamilla) and, as a very remote possibility, the Rio Tinto district in Andalusia (Aguayo de Hoyos 2018; Hernández 2018).

All the districts are already known for the exploitation of their mines in antiquity, in Sardinia and Spain at least since the Bronze age. There is a wide and rich bibliography on the compatibilities between ancient objects and provenance districts for the Bronze and Iron age of

Sardinia (Stos Gale et al 1995; Begemann et al 2001; Atzeni et al 2005; Gale 2006; Giardino and Lo Schiavo 2007), Italian peninsula (Zifferero 1998) and Spain (Craddock et al 1985; Stos Gale et al 1995; Renzi et al 2009, 2012; Rovira and Renzi 2013; Renzi and Rovira Llorens 2015). What is really interesting for Sardinia is the continuity of exploitation of mine districts during the Iron age also in phases which were prior to the establishment of Phoenician colonies in the island.

From an archaeological point of view there emerges, for the first four centuries of the first millennium BCE, a wide and dynamic organization of the exploitation of metals in many parts of the island and a wide circulation of lead inside and outside of the island.

This is quite important because the provenance could have been determined by new contacts and relations with other areas or districts: these contacts could be hypothesized on the basis of the lead found at La Fonteta (Renzi et al 2009: 2584–2596), in Spain, where the semi-worked metal from Catalan Coastal Ranges and from Sierra Alhamilla could have been accumulated in the site and then exported to Sant'Imbenia. These data strengthen the relation between the Iberian peninsula and Sardinia already attested by pottery and amphorae since the end of the ninth c. BC (Rendeli 2018).

Of great importance is the result that the isotopic values of many of the samples are compatible to a good degree with those of ores from mines or mining districts: this means that the lead was not mixed with metal coming from other mines; perhaps it was used once or reused without being blended.

The clamps, which in two occurrences were used to restore large storage vessels of local production, indicate that the lead could have been worked at Sant'Imbenia or in sites nearby. The lead could have arrived in a semi-worked state, similar to the ingots found in the excavation of Sant'Anastasia at Sardara and other S Sardinian sites, then utilized locally to create objects (Ugas 1993: 25–35). While the huge number of laminae, possibly parts of clamps, could have been smelted in situ or nearby, different observations can be made for the two weights, whose metal could have been extracted at Bindua or Buggerru in the Iglesiente (sample 1) and at Montevecchio in the Arburese district (sample 8, 8bis): their life could have been longer and they could have been brought into a Phoenician colony to become part of a set of weights which could have relations with different Aegean and Levantine ponderal systems.

The circulation of lead is also important because it testifies, indirectly, to the organization of local communities in those districts: it offers a new view of the relations among different areas of the island, all under the control of local communities, whose political and economic organization is not known and has yet to be analysed and understood. Quantities are higher in comparison with the previous periods and the communities must have been organized differently, into a network the vitality of which testifies to a real change: their participation in internal as well as international trade and strong relations existing on a regional scale among different political and economic structures. It means also organization of a *chaîne operatoire* that starts from the mines and finishes with the objects and their circulation.

Lead can also be considered a clue for the extraction of silver, separated by cupellation from galena, of which there are rich deposits in Sardinia (Pearce 2018). Control over the mines in this long period (ninth to the mid-sixth centuries BCE) must have been exercised by the local communities, which may have changed their organization with the aim of responding to all the requests.

This means new ways of production, specialization and organization of work, perhaps with the same paths followed by potters, farmers or shepherds. The development of these mining activities in many areas of the island brings new light also to the definition of local organization, with or without the direct help of foreign merchants. The latter may also have triggered the endogenous transformations we can see at Sant'Imbenia or in many other areas all over the island, in the S part with the creation of the Phoenician colonies, in the NE part where the new discoveries at Tavolara, dated to the very early Iron Age, open important perspectives on the relation between the aristocracies of the newly formed Etruscan cities and of the Sardinian state organization (Casi 2018: 6–8; Di Gennaro 2019: 54–57).

Appendix

Table 3 Trace elements of eight Sant'Imbenia lead samples

Sample	US	Ag ppm	As ppm	Sb ppm	Cu ppm	Au ppm	Br ppm
3	A 49 US110	3.0 ± 0.1	0.179 ± 0.013	2.58 ± 0.10	55 ± 7	0.0112 ± 0.0014	1.4 ± 0.2
4	E1 US 1246	1.8 ± 0.1	≤ 0.02	0.58 ± 0.10	77 ± 9	≤ 0.0029	≤ 0.06
9	A 50 US112	10.1 ± 0.5	≤ 0.05	0.83 ± 0.10	270 ± 21	≤ 0.0045	13.0 ± 1.4
10	A 52 US505	2.1 ± 0.1	≤ 0.03	0.76 ± 0.04	29 ± 6	≤ 0.0027	0.3 ± 0.1
11	A 44 US974	5.2 ± 0.3	2.51 ± 0.10	1.75 ± 0.07	85 ± 9	0.0112 ± 0.0020	≤ 0.10
12	A 24 US404	6.7 ± 0.3	≤ 0.03	6.92 ± 0.26	135 ± 13	≤ 0.0039	0.6 ± 0.1
13	A 47 US 135	7.2 ± 0.4	6.00 ± 0.2	1.89 ± 0.09	57 ± 7	0.0060 ± 0.0016	≤ 0.10
17	A 52 US675	3.2 ± 0.2	0.17 ± 0.02	1.46 ± 0.07	72 ± 8	0.0130 ± 0.0025	3.1 ± 0.4

Table 4 Lead relative compositions of Sardinian mining sites, from *Medoresall* database. 1 Boni M, Koeppel V (1985) Ore-lead isotope pattern from the Iglesiente-Sulcis Area (SW Sardinia) and the problem of remobilization of metals. Mineralium Deposita 20: 185–193. 2 Gale NH, Stos-Gale ZA (1987) Oxhide ingots from Sardinia, Crete and Cyprus and the Bronze Age copper trade: new scientific evidence. Studies in Sardinian Archaeology 3. Nuragic Sardinia and the Mycenaean World, BAR IS 387: 159–198. 3 Gale NH, Stos-Gale ZA (1988) Recent evidence for a possible Bronze Age Metal Trade between Sardinia and the Aegean. French EB, Wardle KA eds Problems in Greek Prehistory, Bristol Classical Press, Bristol: 349–384. 4 Ludwig KR, Vollmer R, Turi B, Simmons KR, Perna G (1989) Isotopic constraints on the genesis of base-metal ores in Southern and Central Sardinia. European Journal of Mineralogy 1: 657–666. 5 Stos-Gale ZA, Gale NH, Houghton J, Speakman R (1995) Lead isotope data from the Isotrace Laboratory, Oxford: Archaeometry data base 1, ores from the Western Mediterranean. Archaeometry 37: 407–415

Biblio	Mining site	Mineral	$^{207}Pb/^{206}Pb$	$^{208}Pb/^{206}Pb$	$^{206}Pb/^{204}Pb$
4	Iglesiente, San Giovanni Indina (Bindua, Iglesias)	Galena	0.87422	2.1226	17.881
1	Iglesiente, Carreras (Iglesias, SU)	Galena	0.87420	2.1227	17.909
1	Iglesiente, Medau de Bega (Domusnovas)	Galena	0.87420	2.1234	17.901
1	Fluminese, Monte Serrau	Galena	0.87420	2.1242	17.909
4	Iglesiente, San Giovanni Indina (Bindua, Iglesias)	Galena	0.87419	2.1238	17.884
2	Iglesiente, Acquaresi	Galena	0.87416	2.12074	17.850
4	Iglesiente, Domusnovas (SU)	Galena	0.87414	2.1225	17.901
4	Iglesiente, San Giovanni (Bindua, Iglesias)	Galena	0.87411	2.1207	17.88
4	Fluminese, Gutturu Pala ((Su Zurfuru, Fluminimaggiore)	Galena	0.87413	2.1230	17.871
1	Iglesiente, Monte Arcau	Galena	0.87413	2.1236	17.903
1	Iglesiente, Monte Sa Bagattu	Galena	0.87409	2.1235	17.894
2	Iglesiente, San Giovanni, Masso Pozzo (Bindua, Iglesias)	Galena	0.87406	2.12025	17.869
1	Iglesiente, San Giovanni Massa Pozzo 4 (Bindua, Iglesias)	Galena	0.87404	2.1222	17.894
4	Sassarese, Uri, Sos Agheddos, San Lorenzo mine	Galena	0.87403	2.1226	17.909
5	Iglesiente, San Giovanni (Bindua, Iglesias)	Galena	0.87401	2.12304	17.903
1	Fluminese, Canali Bingias	Galena	0.87401	2.1236	17.898
4	Iglesiente, San Giovanni (Bindua, Iglesias)	Galena	0.87398	2.1218	17.894
1	Fluminese, Gutturu Pala ((Su Zurfuru, Fluminimaggiore)	Galena	0.87394	2.1226	17.896
1	Sulcis, Monte S'Orcu	Galena	0.87388	2.1215	17.895
2	Iglesiente, Carreras (Iglesias, SU)	Galena	0.87387	2.1205	17.889
4	Iglesiente, Masua (Buggerru)	Galena	0.87383	2.1244	17.897
1	Iglesiente, Buggerru, Pira Roma-S. Luigi	Galena	0.87382	2.1223	17.887
2	Iglesiente, San Giovanni, Vene de Telle (Bindua, Iglesias)	Galena	0.87377	2.11947	17.870
2	Iglesiente, San Giovanni (Bindua, Iglesias)	Galena	0.87367	2.1187	17.867
1	Iglesiente, San Benedetto (Marganai, Iglesias)	Galena	0.87367	2.1224	17.905
2–3	Iglesiente, Carreras (Iglesias, SU)	Galena	0.87357	2.11931	17.880
4	Iglesiente, Domusnovas, Macciurru (SU)	Galena	0.87193	2.1201	17.951
4	Fluminese, Su Zurfuru (Fluminimaggiore)	Galena	0.87178	2.1212	17.969

Table 5 Data highlighted from Table 2: 1 Boni M, Koeppel V (1985) Ore-lead isotope pattern from the Iglesiente-Sulcis Area (SW Sardinia) and the problem of remobilization of metals. Mineralium Deposita 20: 185–193

Biblio	Sample	Sample/mineral	$^{207}Pb/^{206}Pb$	$^{208}Pb/^{206}Pb$	$^{206}Pb/^{204}Pb$
	SI_2013_A47_US832 (Sample 1)	Part of weight	0.87397	2.1223	17.903
	SI_2010_A24_US51(Sample 2)	Clamp	0.87389	2.1223	17.902
	Mining site				
1	Iglesiente, Buggerru, Pira Roma-S. Luigi	Galena	0.87382	2.1223	17.887
1	Iglesiente, San Giovanni Massa Pozzo 4 (Bindua, Iglesias)	Galena	0.87404	2.1222	17.894

Table 6 Data from Medoresall database. For Sardinia: 1 Gale NH, Stos-Gale ZA (1987) Oxhide ingots from Sardinia, Crete and Cyprus and the Bronze Age copper trade: new scientific evidence. Studies in Sardinian Archaeology 3. Nuragic Sardinia and the Mycenaean World, BAR IS 387: 159–198. 2 Ludwig KR, Vollmer R, Turi B, Simmons KR, Perna G (1989) Isotopic constraints on the genesis of base-metal ores in Southern and Central Sardinia. European Journal of Mineralogy 1: 657–666. 3 Stos-Gale ZA, Gale NH, Houghton J, Speakman R (1995) Lead isotope data from the Isotrace Laboratory, Oxford: Archaeometry data base 1, ores from the Western Mediterranean. Archaeometry 37: 407–415

Biblio	Country	Mining District	Mine	Ore	$^{207}Pb/^{206}Pb$	$^{208}Pb/^{206}Pb$	$^{206}Pb/^{204}Pb$
1	Sardinia, S-W	Arburese	Montevecchio San Antonio (Guspini –Arbus)	Galena	0.86057	2,1073	18,203
2	Sardinia, S-W	Arburese	Montevecchio Rampa Casargiu (Guspini-Arbus)	Galena	0.86052	2,1090	18,211
3	Sardinia, S-W	Arburese	Montevecchio Sanna (Guspini-Arbus)	Galena	0.86028	2.10698	18.208
3	Sardinia, S-W	Arburese	Montevecchio (Guspini-Arbus)	Galena	0.8602	2.10551	18.179
3	Sardinia, S-W	Arburese	Fenugu Sibiri (Gonnosfanadiga)	Galena	0.86014	2.10412	18.224
3	Sardinia, S-W	Arburese	Fenugu Sibiri (Gonnosfanadiga)	Galena	0.86013	2.10308	18.209
3	Sardinia, S-W	Arburese	Monti Mannu (Villacidro)	Galena	0.86013	2.1056	18.235
3	Sardinia, S-W	Arburese	Montevecchio, Piccalinna (Guspini-Arbus)	Galena	0.86011	2.10539	18.170
3	Sardinia, S-W	Arburese	Monti Mannu (Villacidro)	Galena	0.85978	2.10411	18.232
	Spain, S-W	Huelva	Minas de Rio Tinto	Galena	0.86028	2.10426	18.197
	Spain, S-W	Huelva	Minas de Rio Tinto	Galena	0.85999	2.10356	18.186
	Spain, S-W	Huelva	Minas de Rio Tinto	Galena	0.85983	2.10218	18.172

Table 7 Data from Medoresall database: 1 Boni M, Koeppel V (1985) Ore-lead isotope pattern from the Iglesiente-Sulcis Area (SW Sardinia) and the problem of remobilization of metals. Mineralium Deposita 20: 185–193. 2 Gale NH, Stos-Gale ZA (1987) Oxhide ingots from Sardinia, Crete and Cyprus and the Bronze Age copper trade: new scientific evidence. Studies in Sardinian Archaeology 3. Nuragic Sardinia and the Mycenaean World, BAR IS 387: 159–198. 3 Gale NH, Stos-Gale ZA (1988) Recent evidence for a possible Bronze Age Metal Trade between Sardinia and the Aegean. French EB, Wardle KA eds Problems in Greek Prehistory, Bristol Classical Press, Bristol: 349–384. 4 Ludwig KR, Vollmer R, Turi B, Simmons KR, Perna G (1989) Isotopic constraints on the genesis of base-metal ores in Southern and Central Sardinia. European Journal of Mineralogy 1: 657–666. 5 Stos-Gale ZA, Gale NH (1992) New light on the provenience of the copper oxhide ingots found on Sardinia. Tykot RH, Andrews TK eds, Sardinia in the Mediterranean: A Footprint in the Sea, Sheffield Academic Press, Sheffield: 317–345. 6 Stos-Gale ZA, Gale NH, Houghton J, Speakman R (1995) Lead isotope data from the Isotrace Laboratory, Oxford: Archaeometry data base 1, ores from the Western Mediterranean. Archaeometry 37: 407–415

Biblio	Country	Mining district	Mine	Ore	$^{207}Pb/^{206}Pb$	$^{208}Pb/^{206}Pb$	$^{206}Pb/^{204}Pb$
1	Sardinia, S-W	Sulcis	Rosas-Sa Marchesa (Nuxis, SU)	Galena	0.85826	2.1023	18.252
6	Sardinia, S-W	Sulcis	Sa Marchesa (Nuxis, SU)	Galena, sphalerite	0.85822	2.10101	18.221
6	Sardinia, S-W	Sulcis	Rosas, (Nuxis, SU)	Galena, malachite	0.85814	2.10272	18.283
6	Sardinia, S-W	Sulcis	Rosas, (Nuxis, SU)	Galena, malachite	0.85801	2.10182	18.277
2–3-5	Sardinia, S-W	Sulcis	Rosas, (Narcao, SU)	Galena	0.85799	2.1024	18.259
6	Sardinia, S-W	Sulcis	Sa Marchesa (Nuxis, SU)	Galena, sphalerite	0.85779	2.09738	18.220
6	Sardinia, S-W	Sulcis	Rosas, (Nuxis, SU)	Galena, malachite	0.85769	2.10075	18.245
6	Sardinia, S-W	Sulcis	Rosas, (Nuxis, SU)	Galena, malachite	0.85769	2.09963	18.247
6	Sardinia, S-W	Sulcis	Truba Niedda (Nuxis, SU)	Galena, sphalerite, pyrite	0.85767	2.10014	18.250
5	Sardinia, S-W	Sulcis	Truba Niedda (Nuxis, SU)	Galena	0.85742	2.09804	18.232
6	Sardinia, S-W	Sulcis	Rosas, (Nuxis, SU)	Galena, malachite	0.85740	2.09914	18.246
3	Sardinia, S-W	Sulcis	Monte Tamara	Galena; sphalerite	0.85739	2.10256	18.357
5	Sardinia, S-W	Sulcis	Rosas, (Nuxis, SU)	Galena, malachite	0.85738	2.09861	18.237
6	Sardinia, S-W	Sulcis	Truba Niedda (Nuxis, SU)	Galena, sphalerite, pyrite,	0.85724	2.09804	18.232
1	Sardinia, S-W	Sulcis	Narcao, M. Atzei-S. Croce	Galena	0.85715	2.1001	18.257
2–3-5	Sardinia, S-W	Sulcis	Sa Marchesa (Nuxis, SU)	Galena	0.85698	2.09737	18.290
4	Sardinia, S-W	Sulcis	Mont'Ega (Narcao)	Galena	0.85627	2.1020	18.298

Table 8 Data from Medoresall database: 1 Gale NH, Stos-Gale ZA (1987) Oxhide ingots from Sardinia, Crete and Cyprus and the Bronze Age copper trade: new scientific evidence. Studies in Sardinian Archaeology 3. Nuragic Sardinia and the Mycenaean World, BAR IS 387: 159–198. 2 Gale NH, Stos-Gale ZA (1988) Recent evidence for a possible Bronze Age Metal Trade between Sardinia and the Aegean. French EB, Wardle KA eds Problems in Greek Prehistory, Bristol Classical Press, Bristol: 349–384. 3 Stos-Gale ZA, Gale NH (1992) New light on the provenience of the copper oxhide ingots found on Sardinia. Tykot RH, Andrews TK eds, Sardinia in the Mediterranean: A Footprint in the Sea, Sheffield Academic Press, Sheffield: 317–345. 4 Stos-Gale ZA, Gale NH, Houghton J, Speakman R (1995) Lead isotope data from the Isotrace Laboratory, Oxford: Archaeometry data base 1, ores from the Western Mediterranean. Archaeometry 37: 407–415

Biblio	Country	Mining district	Mine	Ore	$^{207}Pb/^{206}Pb$	$^{208}Pb/^{206}Pb$	$^{206}Pb/^{204}Pb$
1–2	Sardinia, N-W	Sassarese	Argentiera, Nurra	Tetrahedrite	0.85758	2.10624	18.233
1–2	Sardinia, N-W	Sassarese	Argentiera, Nurra	Galena	0.85667	2.10683	18.310
1–2	Sardinia, N-W	Sassarese	Argentiera, Nurra	Galena	0.85609	2.10564	18.278
3	Sardinia, S-E	Sarrabus-Gerrei	Pranu e'Sanguini	Galena, sphalerite	0.85813	2.10498	18.321
3	Sardinia, S-E	Sarrabus-Gerrei	Pranu e'Sanguini	Galena, sphalerite	0.85637	2.10156	18.300
4	Sardinia, S-E	Sarrabus-Gerrei	Pranu e'Sanguini	Galena, sphalerite	0.85635	2.10156	18.324
3	Sardinia, S-E	Sarrabus-Gerrei	Pranu e'Sanguini	Galena	0.85635	2.10156	18.234
4	Sardinia, S-E	Sarrabus-Gerrei	Pranu e'Sanguini	Galena, sphalerite	0.85622	2.10099	18.317
4	Sardinia, S-E	Sarrabus-Gerrei	Pranu e'Sanguini	Galena, sphalerite	0.85619	2.10007	18.296
4	Sardinia, S-E	Sarrabus-Gerrei	Pranu e'Sanguini	Galena, sphalerite	0.85611	2.10012	18.290
4	Sardinia, S-E	Sarrabus-Gerrei	Pranu e'Sanguini	Galena, sphalerite	0.85582	2.09782	18.280

Table 9 Montero-Ruiz, I (2017) La Solana del Bepo from an archaeometallurgical perspective. Rafel, N., Soriano, I. Delgado-Raack, S (edd) A prehistoric copper mine in the Noth-East of the Iberian Peninsula: Solana del Bepo (Uldemolins, Tarragona). Revista de Arqueologia de Ponet, extra 2: 65–79

Country	Mining district	Mine	Ore	$^{207}Pb/^{206}Pb$	$^{208}Pb/^{206}Pb$	$^{206}Pb/^{204}Pb$
Spain	Catalan Coastal Ranges	Barranco Hondo	Galena	0.85646	2.1024	18.310
Spain	Catalan Coastal Ranges	Mineralogia	Galena	0.85638	2.1029	18.318
Spain	Catalan Coastal Ranges	Jalapa	Galena	0.85631	2.1021	18.311
Spain	Catalan Coastal Ranges	Mina Regia	Galena	0.85631	2.1015	18.301
Spain	Catalan Coastal Ranges	Linda Mariquita	Galena	0.85624	2.1026	18.322
Spain	Catalan Coastal Ranges	Mineralogia	Galena	0.85624	2.1019	18.309
Spain	Catalan Coastal Ranges	Cueva del Paraguas	Galena	0.85616	2.1011	18.299
Spain	Catalan Coastal Ranges	Linda Mariquita	Galena	0.85609	2.1019	18.316
Spain	Catalan Coastal Ranges	Mineralogia	Galena	0.85609	2.1011	18.301
Spain	Catalan Coastal Ranges	Barranco Hondo	Galena	0.85609	2.1017	18.313
Spain	Catalan Coastal Ranges	Raimunda	Galena	0.85594	2.1024	18.333
Spain	Catalan Coastal Ranges	Raimunda	Galena	0.85587	2.1024	18.333
Spain	Catalan Coastal Ranges	Barranco Hondo	Galena	0.85580	2.1004	18.301
Spain	Catalan Coastal Ranges	Linda Mariquita	Galena	0.85572	2.1013	18.323
Spain	Catalan Coastal Ranges	Linda Mariquita	Galena	0.85565	2.1011	18.322
Spain	Catalan Coastal Ranges	Raimunda	Galena	0.85565	2.1010	18.317
Spain	Catalan Coastal Ranges	Linda Mariquita	Galena	0.85536	2.0999	18.308
Spain	Catalan Coastal Ranges	Linda Mariquita	Galena	0.85521	2.0994	18.316
Spain	Catalan Coastal Ranges	Linda Mariquita	Galena	0.85514	2.1027	18.353
Spain	Catalan Coastal Ranges	Linda Mariquita	Galena	0.85477	2.0996	18.338

Table 10 New data from LIMS

Country	Mining District	Mine	Ore	$^{207}Pb/^{206}Pb$	$^{208}Pb/^{206}Pb$	$^{206}Pb/^{204}Pb$
Spain	Sierra Morena	Azuaga-Fuenteovejuna	Galena	0.85800	2.1061	18.206
Spain	Sierra Morena	Azuaga-Fuenteovejuna	Galena	0.85785	2.1089	18.194
Spain	Sierra Morena	Linares (La Carolina)	Galena	0.85778	2.1058	18.188

Table 11 Data from Medoresall database: 1 Gale NH, Stos-Gale ZA (1987) Oxhide ingots from Sardinia, Crete and Cyprus and the Bronze Age copper trade: new scientific evidence. Studies in Sardinian Archaeology 3. Nuragic Sardinia and the Mycenaean World, BAR IS 387: 159–198. 2 Gale NH, Stos-Gale ZA (1988) Recent evidence for a possible Bronze Age Metal Trade between Sardinia and the Aegean. French EB, Wardle KA eds Problems in Greek Prehistory, Bristol Classical Press, Bristol: 349–384. 3 Stos-Gale ZA, Gale NH (1992) New light on the provenience of the copper oxhide ingots found on Sardinia. Tykot RH, Andrews TK eds, Sardinia in the Mediterranean: A Footprint in the Sea, Sheffield Academic Press, Sheffield: 317–345. 4 Stos-Gale ZA, Gale NH, Houghton J, Speakman R (1995) Lead isotope data from the Isotrace Laboratory, Oxford: Archaeometry data base 1, ores from the Western Mediterranean. Archaeometry 37: 407–415

Biblio	Country	Mining district	Mine	Ore	$^{207}Pb/^{206}Pb$	$^{208}Pb/^{206}Pb$	$^{206}Pb/^{204}Pb$
4	Central Sardinia	Barbagia	Funtana Raminosa	Galena, sphalerite	0.85773	2.09861	18.212
4	Central Sardinia	Barbagia	Funtana Raminosa (Gal. Yvonne no. 3)	Galena (silver), sphalerite	0.85737	2.09758	18.197
1–2-3	Central Sardinia	Barbagia	Funtana Raminosa	Galena	0.85694	2.09758	18.197
4	Central Sardinia	Barbagia	Funtana Raminosa	Galena (silver), sphalerite	0.85676	2.09895	18.254
4	Central Sardinia	Barbagia	Funtana Raminosa	Galena, chalcopyrite	0.85599	2.09502	18.203
1–2	Central Sardinia	Barbagia	Funtana Raminosa	Galena; sphalerite	0.85448	2.09413	18.293

Table 12 Montero-Ruiz, I (2017) La Solana del Bepo from an archaeometallurgical perspective. Rafel, N., Soriano, I. Delgado-Raack, S (edd) A prehistoric copper mine in the Noth-East of the Iberian Peninsula: Solana del Bepo (Uldemolins, Tarragona). Revista de Arqueologia de Ponet, extra 2: 65–79; Sardinia: Oxalid Italy, Sample, Sard 49A

Country	Mining district		Ore	Mine	$^{207}Pb/^{206}Pb$	$^{208}Pb/^{206}Pb$	$^{206}Pb/^{204}Pb$
Spain	Catalan Coastal Ranges	MBF	Galena	Linda Mariquita	0.85448	2.1003	18.357
Spain	Catalan Coastal Ranges	Montsant	Galena	Mina Besso	0.85412	2.0970	18.352
Spain	Catalan Coastal Ranges	MBF	Galena	Balcoll	0.85404	2.0986	18.358
Spain	Catalan Coastal Ranges	MBF	Silver	Balcoll	0.85353	2.0971	18.358
Italy	Sardinia	Barbagia	Galena	Funtana Raminosa	0.85455	2.0924	18.293
Spain	Sierra Morena	Pedroches	Galena	La Atalaya (CO 12) Alcaracejos	0.85448	2.1015	18.262
Spain	Sierra Morena	Pedroches	Galena	Miniera El Soldado (CO 109)	0.85383	2.1007	18.327
Spain	South-East	Sierra de Alhamilla	Galena	Pantano Nìjar	0.85463	2.1006	18.327
Spain	South-East	Sierra de Alhamilla	Galena	Coto Laisquez	0.85463	2.1005	18.323
Spain	South-East	Sierra de Alhamilla	Galena	Coto Laisquez	0.85463	2.1005	18.321
Spain	South-East	Sierra de Gador	Galena	Tolva	0.85455	2.1030	18.339
Spain	South-East	Cartagena	Galena	Sierra de Cartagena, Filone San Juliàn	0.85412	2.0998	18.321
Spain	South-West	Huelva	Pb	Rio Tinto (H43), Cueva del Lago	0.85455	2.1022	18.348

Table 13 Antolinos Marin JA, Domergue C, Manteca JI, Palero Fernández FJ, Quarati P, Rico C, Stefanile M, Trincherini PR (in press) Lateres Plumbei Hispani. Production et commerce du plomb hispanique à l'époque romaine (II^{e} s. av. J.-C. – II^{e} s. ap. J.-C.), Ed. Casa de Velásquez, Madrid. (accepted November 2020); Arribas and Tosdal 1994

Spain	Mining district		Ore	Mine	$^{206}Pb/^{207}Pb$	$^{208}Pb/^{206}Pb$	$^{206}Pb/^{204}Pb$
Central-East	Castellón	Plana Alta	Galena	Torre de la Sal	0.84069	2.0838	18.657
Central-East	Castellón	Plana Alta	Lead	Torre de la Sal	0.83780	2.0841	18.731
Central-East	Castellón	Plana Alta	Lead	Torre de la Sal	0.83710	2.0835	18.747
Sierra Morena	Azuaga-Fuenteovejuna	Fuenteovejuna	Lead	La Loba (CO 55), Village	0.83773	2.0840	18.709
South-East	Cartagena-Mazarrón	Cartagena	Scoria	La Balsa	0.83963	2.0886	18.768
South-East	Cartagena-Mazarrón	Cartagena	Galena	S.Valentin	0.83949	2.0877	18.774
South-East	Cartagena-Mazarrón	Cartagena	Galena	Navidad	0.83759	2.0837	18.722
South-East	Cartagena-Mazarrón	Cartagena	Galena	Cabezo Rajado	0.83752	2.0840	18.739
South-East	Cartagena-Mazarrón	Cartagena	Galena (manto)	Cartagena (MU3)	0.83731	2.0832	18.707
South-East	Cartagena-Mazarrón	Mazarrón	Galena	San Cristobal	0.83710	2.0842	18.765
South-East	Cartagena-Mazarrón	Cartagena	Scoria	Cala Reona Sierra de Cartagena	0.83605	2.0832	18.693
South-West	Huelva	Cinture pyriteuse du Sud-Ouest	Lead (n°21.67)	Cueva del Lago (Rio Tinto)	0.83752	2.0839	18.728

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Author contribution M.Ca. and E.F. coordinated the scientific project, organized the different parts of the team, and gave important criticisms and advices; I.M.V., P.R.T, M.Cl., S.N., M.F., V.S., and P.O. were part of the two teams, LNGS and Università di Milano Bicocca, who made the measures and produced the text; B.B., G.G., and M.R. constituted the archaeological part of the team, both of the Soprintendenza Archeologia, Belle Arti e Paesaggio per le province di Sassari e Nuoro, and Università di Sassari, which have the co-direction of the archaeological project.

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