Mediterranean Archaeology and Archaeometry, Vol. 19, No 1, (2019), pp. 9-24
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www.maajournal.com

DOI: 10.5281/zenodo.2585944

NEW BRONZE AGE ABSOLUTE DATINGS FOR SOLANA DEL BEPO COPPER MINE (ULLDEMOLINS, TARRAGONA PROVINCE, SPAIN)

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Received: 15/02/2018
Accepted: 29/01/2019
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ABSTRACT

We present the results of the archaeological excavation carried out at the Solana del Bepo mine that have allowed us to contextualise the surface finds made in the 1940s. It had been possible to locate the prehistoric workings and to characterise the mined ores by pXRF elemental, μ-XRF and LIA analyses. The mining implements found in the excavation and the earlier surface finds were typologically described and classified. To precise the chronology a set of samples were radiocarbon dated. The results confirm that Solana del Bepo was an active copper mine at least throughout the first half of the second millennium cal BCE, that is the Early/Middle Bronze Age of northeast of the Iberian Peninsula. The studies carried out there and in other mines in the county of Priorat (province of Tarragona) allow us to advance some considerations regarding the nature of the exploitation of local copper ore, its chronology and the regional dispersion of the metal obtained.

KEYWORDS: Mining, Early- to Middle-Bronze Age, mining picks, composition analysis, lead isotopes analysis, copper ore circulation

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To Rosa Maria Mercado Guirado († 06/08/2018)

1. BACKGROUND

Solana del Bepo mine (Figure 1) has been known since the late 1940s, when Salvador Vilaseca undertook a brief survey in which he collected some fragments of copper carbonates and more than 80 macrolithic tools, mainly mining picks. Years later, a brief report on the find was published (Vilaseca and Vilaseca, 1957) and since then the mine has been an obligatory reference point for any study of prehistoric mining on the Iberian Peninsula (Domergue, 1987: 483; Martín *et al.,* 1999: 159; Maya, 2002: 95; Montero and Rodríguez de la Esperanza, 2004; Rodríguez de la Esperanza, 2005: 59; Rovira Hortalà, 2006: 138; Genera, 2007; Genera, 2011; Soriano, 2013: 61; O'Brien, 2015: 103). Vilaseca had it "in mind" to publish the study of the find, but he never got round to it, meaning that until now the aforementioned brief summary was the only publication on the archaeological site. However, within the framework of our projects on prehistoric mining in north-eastern Spain, we have recently published an exhaustive study of Vilaseca's finds and other subsequent surface finds (Rafel *et al.,* 2016; Rafel, Delgado-Raack and Soriano, 2017). This gives them a contextual framework (Rafel and Soriano, 2017a), offering a study and a catalogue of the macrolithic implements discovered (Delgado-Raack and Gómez-Gras, 2017 and Delgado-Raack and Soriano, 2017). It also contains an archaeometric study within the framework of the compositional and isotopic characterisation of the mines of the Montsant basin –of which Solana del Bepo is one– and compares it with the manufactured metal finds made in the area (Montero, 2017). In chronological terms, we suggested situating the mine in a temporal lapse between the Late Chalcolithic and the Middle Bronze Age (Rafel and Soriano, 2017b: 90), based on both indirect and contextual data, especially from archaeometry. Despite the importance of the assemblage of mining implements found, until now no excavation data with absolute datings had been available.

Figure 1. General location of Solana del Bepo mine

The large number of stone tools collected systematically on the surface by Vilaseca and subsequent visitors to Solana del Bepo contrasted in the prospections undertaken with the extreme lack of minerals and the absence of evidence of mine workings on land that has since been prepared for farming and is currently used to cultivate hazelnut trees (Figure 2). The technological study of the pick assemblage has allowed us to define their main morphotechnical features (Figure 3) (Delgado-Raack and Gómez-Gras, 2017). Morphologically, the picks can be divided into a predominant group with a pointed vertex and a minority group with a bevelled vertex, for the manufacture of which granitic rocks or rocks affected to a greater or lesser extent by contact metamorphism were used. One of the most characteristic features of this find assemblage is the high degree to which the natural supports were transformed prior to use. This is evidenced by the preparation of the passive faces and the installation of haft fittings. The two main forms in which these fittings are manifested are grooves and notches. The use of one or the other depended on the metric characteristics of the support, grooves normally being associated with massive picks and notches with flat picks. Their presence on all the picks that preserve the proximal third (except for two preforms that do not have them) indicates that those tools were designed to be fitted with a haft from the outset of their operational life.

Figure 2. View of the archaeological site before the 2016 excavation

The active fronts are affected by percussion marks caused by strong impacts against a hard contact material that led to the blunting of the working surface. In addition, copper residue has been identified on some of the percussion heads. This, together with the qualitative characteristics of the wear and the contextual information attributed to the picks, supports their functional interpretation as basic working tools for copper ore mining. A study of the metric variables and morphology of the working surfaces has led to the conclusion that they are percussion tools with different degrees of wear, rather than types conceived as such. These degrees of wear reflect diverse moments in the useful life of the picks (the wear process). In a simplified model, this would be their state as a preform, a slightly worn tool, a very worn tool, a fractured artefact and a recycled artefact.

Figure 3. Selection of picks from the collection recovered prior to the 2016 archaeological intervention

In summary, the high degree of transformation presented by the picks, both due to the preparation of the support and their use as a working tool, indicates an intensive activity involving them. Although the raw materials used in their manufacture are found in abundance around the archaeological site, there was a major investment in the prior preparation of the artefact, probably with the aim of extracting the ore in optimum conditions and within the framework of specialised working processes. Once the pick had been worn out or broken, to a certain extent the prolongation of its use was accomplished under the criterion of a deep-seated technical knowledge of the rocks and their behaviour. This is attested by the retouching of fracture planes, the reconditioning of percussion heads and the reuse of the haft fittings, despite the loss of the artefact's general morphology. It is precisely this that constitutes one of the fundamental differences with respect to other Spanish and European mines, where the tools were discarded once broken (Hunt Ortiz, 2003: 285) and they present a much lower degree of transformation than those of Solana del Bepo (these mines are listed in Rafel and Soriano, 2017b: 85-86). Merely by way of an example, we should point out that the closest morphological parallels we have documented correspond to very ancient mines. They are, firstly, the Duzdaği salt mine (Nakhchivan, Azerbaijan) dated to between the fifth and the third millennium cal BC (Hamon, 2016). To this, we should add the exploitation of iron hydroxides (goethite and lepidocrocite) and copper ores (mainly malachite, azurite and perhaps brochantite) at Grotta della Monaca (Calabria, Italy), dated to between the late-fifth and mid-fourth millennium cal BC (Breglia, Caricola and Larocca, 2016; Quarta *et al.*, 2013).

2. THE 2016 ARCHAEOLOGICAL INTERVENTION

With the main aim of locating the prehistoric works and establishing its chronology, in September 2016 an archaeological excavation consisting of two large parallel trenches was carried out at the site (Figure 4). One of the trenches (T2) turned out to be infertile in archaeological terms, although some stone mining implements were recovered on more modern levels as a result of farming disturbance. In contrast, in the other trench (T1), which was almost 33 metres long, mining works were documented. It was open cast in the form of a broad trench segmented transversally in which we documented prehistoric archaeological levels with new lithic items and organic remains suitable for radiometric dating. The work was carried out using mechanical methods to the relative level of -4.00 m and manually, by means of a reduced sounding, without reaching the geological substrate, to a depth of 6.20 m (Figure 5, Figure 6).

Figure 4. General view of the two trenches

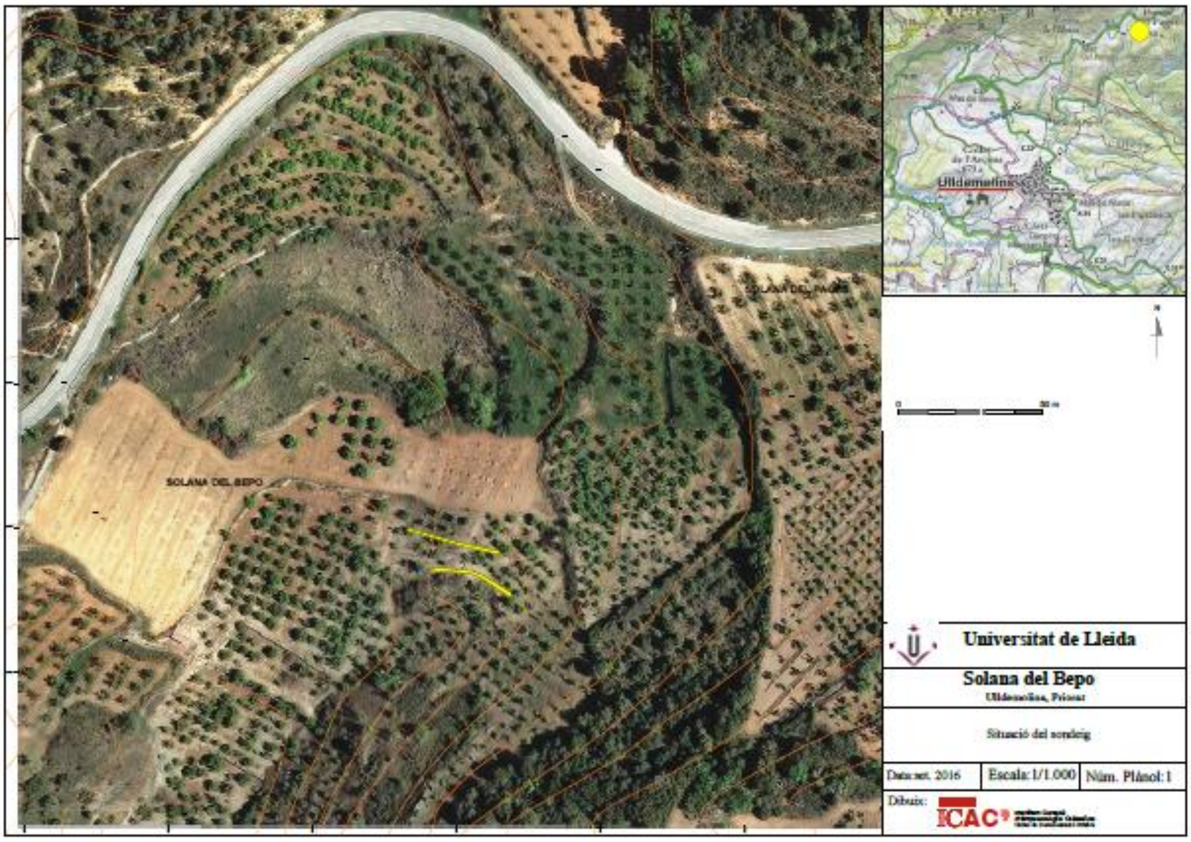

Figure 5. Regional and topographical situation of the excavation of Solana del Bepo. Yellow lines indicate trenches T1 (upper) and 2 (lower)

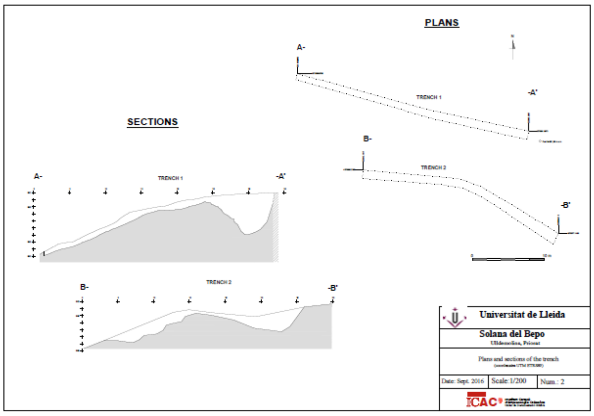

Figure 6. Ground plan and sections of trenches 1 and 2

While the excavation, a total of 12 mining picks was found. Most of them still had the proximal third with the traces of the haft grooves/notches documented among the items recovered by Vilaseca. In this way, thanks to the recent excavations, we have been able to rule out the suggestion that Vilaseca's collection was the result of a selective gathering of artefacts that prioritised the most obviously anthropogenically transformed examples. Consequently, we can now confirm that the artefacts in that collection are representative of the Solana del Bepo archaeological deposit.

The archaeological intervention has also confirmed that what, since Vilaseca's time, had been thought to be the ancient mine spoil tip (Rafel and Soriano, 2017: Fig. 3) is in fact modern fill levels related to the terracing of the land for cultivation. These levels are of considerable depth and consist mainly of fragments of the slate that makes up the geological substrate that crops out in the zone. The slate levels, transported from nearby unmineralised areas, completely covered the mine workings. Those mine workings would have been associated with the filonian mineralisation that runs from north to south, the same direction as the neighbouring El Bessó mineralisation. Solana del Bepo's geological context is largely made up of slates affected to a greater or lesser extent by contact metamorphism from the Carboniferous-Permian, above which, locally, are limestones of the Cornudella Group from the Palaeocene-Eocene (Delgado-Raack and Gómez-Gras, 2017: fig. 27). At the bottom of Trench T2 (in which a maximum depth of 3 m was reached) along its whole length it reached the geological base, the unmineralised slate. In Trench 1, in contrast, the slate was divided into sections by the mine workings, and appeared very disturbed, almost clayey, and with yellowish-reddish colourings in the western zone, where the highest conserved level is situated. In the area of the wall at the eastern end of Trench T1 the slate appeared compact and undisturbed, with a grey-bluish colour. The intermediate area, that of contact, was where the mining works were carried out. That led to it being emptied to the lowest excavated level to access the mineralisation. Strictly speaking, we did not reach the bottom of the mine workings, the interior of which was clogged up by a complex succession of levels, of which the lowest detected in the sondage contained abundant signs of minerals. This is evidence that we are dealing with a chalcopyrite mineralisation with associated quartz; it is very weathered and has predominance of secondary formation minerals, and especially of copper carbonates (both malachite and azurite) and iron oxides, although frequently of millimetric size and mixed with a matrix of clays.

The longest and deepest upper stratigraphic units in Trench T1 (SUs 1 to 3, 4) correspond to fill levels composed mainly of slate fragments deposited intentionally in more or less recent times to level the terrain and build even platforms for agricultural use (Figure 7).

These levels, which reach a maximum depth of around 4 m, cover a series of strata, the uppermost conserved of which are deposited on the divided geological level, with a marked dip towards the interior of the mine workings. To a greater or lesser extent, these strata, like SU 7, have a clayey matrix, with centimetre-sized fragments of slate and inclusions of small lumps of malachite, azurite and iron oxides. In other cases, the mid-sized fragments of slate predominate (SU 17). In any case, they are the result of successive depositions linked to the prehistoric mining and attest a complex stratigraphic series; due to the limited excavation area, we were unable to determine the total number. What we do consider possible, an aspect that will be supported by the absolute datings given below, is that there was a partial extraction of earlier depositional levels during subsequent working. This would be the case of SU 7, which would have been partially affected by subsequent workings and refilling. Trench T1, dug as indicated from east to west, revealed a transversal section of the mine workings, which ran in this area from north to south.

The original geological level (SU 20) presents a very vertical anthropogenic cut with a depth of more than 4.5 m and a maximum width of almost 10 m in the area nearer the surface. This had been dug to exploit the mineralised vein. The prehistoric levels provided a small collection of mining picks in stratigraphic context. We also documented samples of the primary (chalcopyrite) and secondary copper minerals (carbonates: malachite and azurite). Moreover, charcoal was also found associated with one of the stone picks located in the lower levels of the excavation. The charcoal, a good-sized fragment (*c.* 15 mm.), was found adhered to the proximal part of the pick from SU 15 (Figure 8), meaning that it could well have been the remains of the haft fitting. It is charcoal from *Pinus silvestris* or *Pinus Nigra*, a type of wood found in other SUs of the stratigraphic cut, and is especially abundant in SU 7.

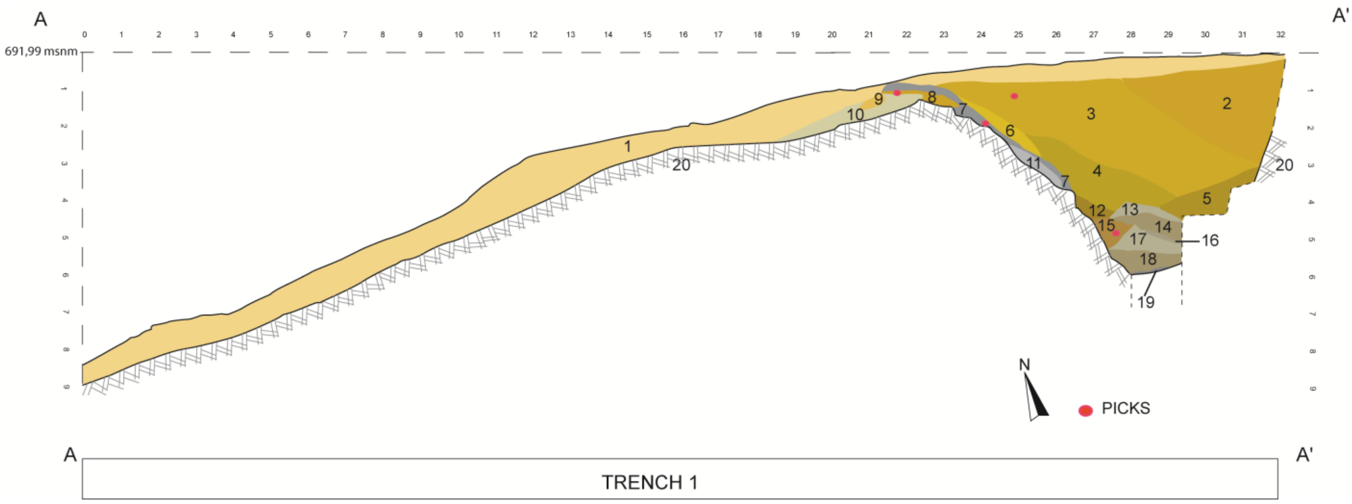

Figure 7. Stratigraphic section A-A' of Trench T1 with numbers indicating SUs

Figure 8. Proximal half of the pick in SU 15, the lower part of which had pine charcoal adhered to it that was subsequently radiocarbon dated

3. THE ABSOLUTE DATINGS

Three radiometric datings were made (Table 1), two of the carbonised pine wood, of which the first (Beta 44528) corresponds to small fibres recovered from the sediment in SU 7, while the second (Beta 44529) was carried out on the charcoal adhered to the proximal end of the stone mining implement found in SU 15. The third dated sample corresponds to organic sediment from SU 18 (Beta 44530). The sample from SU 7 is dated, calibrated to two-sigma and with 100% probability, between 1953 and 1768 cal BCE, whereas the sample from SU 15 is situated, at two-sigma and with 100% of probability, between 1742 and 1536 cal BCE (although between 1700 and 1606 with 83% of probability) and to one-sigma and with 100% of probability between 1687 and 1622 cal BCE. Consequently, SU 7 gives an earlier dating than SU 15, which would confirm the aforementioned possibility of subsequent workings affecting the earlier levels. The third sample gives a much earlier date in the second half of the 4th millennium cal BCE. From a contextual point of view, the most reliable sample is the charcoal from SU 15 associated with the mining pick found in that stratigraphic unit. For that reason and the fact that it is the most recent date, we are inclined to think that it corresponds to one of the periods of the prehistoric exploitation, in the 17th century cal BCE. The sample from SU 7 would represent a somewhat earlier mining phase, whose depositional levels would have been partially cut through by the mining works of that second exploitation. Finally, in the absence of other data that could support such an early exploitation phase and due to the specific nature of the sample, for the time being we must treat with caution the date obtained from the SU 18 sediment, that places it in the second half of the fourth millennium cal BCE.

Consequently, and without taking into account the date that places the beginnings of the mining in the 4th millennium cal BCE, we are looking at a copper mineralisation that was almost certainly exploited in different phases during the first half of the 2nd millennium cal BCE (Figure 9). In the survey of the Solana del Bepo area we were able to see small veins with the same orientation as that documented in the excavation, some of which were possibly also exploited in chronologies that could be contemporary with the vein we found, although they could also expand the chronological range of the workings. As we have no evidence of this for the time being, we have to place the Solana del Bepo mine chronologically in the transitional period between the Early- and Middle-Bronze Ages, based on the radiocarbon dates, which do not contradict what we had already observed in relation to the archaeometric and contextual aspects (Rafel and Soriano, 2017b).

Table 1. The three radiocarbon datings calibrated with Calib Rev. 1 and IntCal 13 (Reimer et al., 2013)

UE	nº	Radiocarbon Age	Material	1s Calibration	2s Calibration
7	Beta 47528	3540+30	Charcoal	1931-1876 (64,2%) 1842-1819 (20,9%) 1797-1781 (14,7%)	1953-1768 (100%)
15	Beta 47529	3360+30	Charcoal	1687-1622 (100%)	1742-1710 (10,6%) 1700-1606 (83,4%) 1583-1558 (4,8%) 1554-1546 (0,9%) 1536-1536 (0,1%)
18	Beta 47530	4570+30	Organic sediment	3369-3334 (63,4%) 3211-3191 (21,2%) 3153-3135 (15,2%)	3493-3468 (6,5%) 3374-3319 (49,3%) 3292-3290 (0,07%) 3273-3268 0,44%) 3236-3168 (24%) 3165-3110 (19,5%)

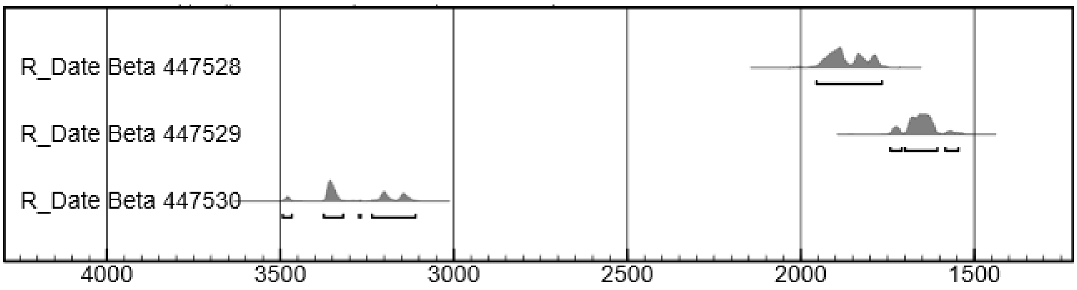

Figure 9. Radiocarbon datings (Cal BC) of Solana del Bepo. Oxcal v. 4.3.2, Intcal 13 (Reimer et al. 2013)

4. THE ORES MINED

Before the archaeological intervention, the collection of surface samples from the supposed spoil tips had allowed a very general characterisation of the type of copper ore exploited at Solana del Bepo (Montero Ruiz, 2017). As previously stated, due to the considerable alteration of the terrain when it was terraced for agricultural purposes, the studied samples were of limited quality, although finally, in addition to malachite, we were able to identify the formation of secondary sulphurs that tend to appear in the enrichment zones, such as djurleite [$Cu_{31}S_{16}$]. The samples collected during the excavation, linked directly with the exploited vein, add considerable information to the mineralogical description of Solana del Bepo, as copper sulphides such as chalcopyrite crystalline phases was made through X-ray diffraction (XRD) at CENIM-CSIC using a Bruker AXS Model D8 Advance X-ray diffractometer with a Co tube and Goebel mirror optics to obtain a parallel monochromatic beam. The applied working conditions were 40 kV and 30 mA and the measurement time and incremental steps were optimised to obtain high-quality diffractograms with a suitable score statistic, acute diffraction peaks, and good resolution, as well as guaranteed detection of minority phases. The tests were carried out on a range of 10 to 110º in 2θ and a step of 0.015º. The samples were ground and the diffractograms were adjusted using the Rietveld method. The results of the identified phases are shown in Table 2.

The phases of secondary sulphurs identified, in addition to covellite, belong mainly to the Chalcocite-Digenite group, including the aforementioned djurleite. The gangue is quartz.

The elemental characterisation was carried out using portable X-ray fluorescence equipment pXRF)[1]. This allowed a comprehensive evaluation of the light elements (LE) and the identification of the metallic elements that may have made up the metal obtained from the reduction of those ores. Although the results of the table are shown in % weight, the values must be considered as semiquantitative and their relative presence evaluated in relation to the copper to understand the possible characteristics of the metal that would have been obtained after reduction.

Table 2 shows the values of the twelve samples selected to demonstrate the mineralogical diversity (with *de visu* textural and chromatic differences) of the mineral samples retrieved during the excavation and the three samples collected on the surface during the preparation work.

Although there is a predominance of greenish tones of differing intensities (linked mainly to malachite), blueish, reddish and greyish tones can also be identified (Figure 10). When the sample was large enough, different analysis were made on various surface areas; they are identified by a letter after the number. The identifier SB refers to the stratum the sample came from and is linked to Figure 7 of the stratigraphy in T1. The proportion of light elements is an indicator of the relative richness of the sample. If the proportion of light elements is lower than 25%, the elements are quantified directly at 100%, without considering that percentage, and this corresponds to the highest quality samples.

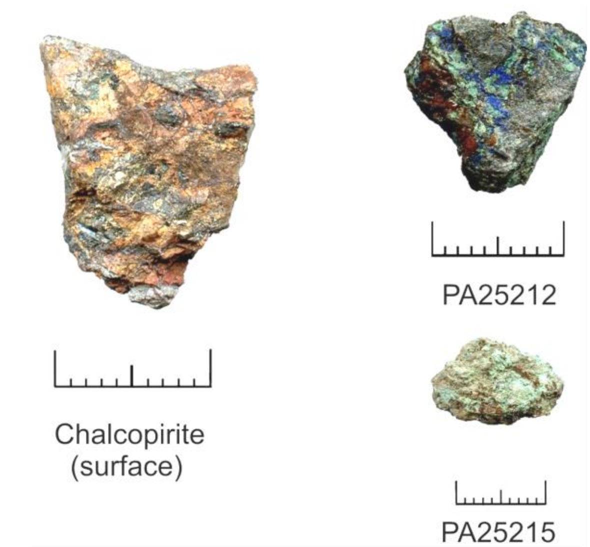

Figure 10. Sulphide and carbonate copper minerals

In summary, copper and iron predominate in the ores, although proportions of zinc and lead are also identified in more than half of the samples. In the analyses in which lead is detected, it is usually accompanied by bismuth. Of particular note is the presence of cobalt in some cases, such as in samples PA25206 and PA25208. It is found in quite high proportions (> 1%), whereas the rest of the elements (Ni, As, Sb, Ag, Sn) are absent or only present in marginal amounts. The evaluation of silver and antimony was limited by the high detection level of the spectrometer, which used a silver anode. Arsenic, a key element in prehistoric metallurgy, was residual, as commented with regard to the previous samples (Montero Ruiz, 2017).

The reduction of these ores could, in certain circumstances, produce a metal with low percentages of arsenic (<0.2 % As), but in no case would arsenicated coppers be obtained. Given the described characteristics of the ores, the metal obtained from Solana del Bepo would have been a relatively pure copper (> 99%) that could have contained small proportions or traces of arsenic and some of the other elements mentioned (especially lead).

These 15 samples were also subjected to lead isotope analysis at the University of the Basque Country's Geochronology Laboratory in a MC-ICP-MS Neptune spectrometer (Thermo Fisher Scientific) (Table 3). Together with the three already published, they make up an assemblage of 18 isotopic results that allow the isotopic field of Solana del Bepo to be well defined. Its relationship with metallurgical objects and remains is discussed below, in Section 6.

Table 2. Composition analysis of ores from 2016 excavation

Num.	Ore	SU	Fe	Ni	Cu	Zn	As	Ag	Sn	Sb	Pb	Bi	LE	Mn	Co
PA25202	Cu chalcopyrite	SB-15	8,07	nd	8,4	nd	0,02	nd	nd	nd	0,05	0,3	82,9	0,2	0,1
PA25203	Cu light green	SB-15	10,9	nd	88,4	nd	0,08	nd	nd	nd	0,07	nd	nd	0,6	nd
PA25203b	Cu light green	SB-15	21,0	nd	7,83	nd	0,01	nd	nd	nd	nd	nd	70,6	0,9	0,3
PA25204	Cu green	SB-18	11,0	nd	84,7	1,93	0,1	nd	nd	nd	0,26	0,2	nd	1,0	0,9
PA25205	Cu red	SB-18	51,9	nd	41,2	0,20	nd	nd	0,5	nd	4,64	1,5	nd	nd	nd
PA25205B	Cu red	SB-18	39,9	nd	51,9	0,25	nd	nd	0,3	nd	3,97	3,4	nd	nd	0,3
PA25206	Cu red	SB-18	11,3	nd	7,75	0,29	0,01	nd	nd	nd	0,07	nd	78,0	0,5	2,0
PA25206B	Cu green	SB-18	9,84	nd	9,94	0,17	0,01	nd	nd	nd	nd	nd	78,3	1,0	0,2
PA25207	Cu green	SB-18	9,07	0,02	4,9	0,13	0,01	nd	nd	nd	0,04	nd	85,0	0,7	0,2
PA25208	Cu complex zone	SB-18	17,7	nd	9,5	0,17	0,03	nd	nd	nd	0,19	nd	72,2	0,4	0,1
PA25208B	Cu mix colors	SB-18	5,27	nd	3,0	0,20	nd	nd	nd	nd	0,08	nd	87,1	1,1	2,7
PA25208C	Cu orange	SB-18	4,83	nd	1,56	0,04	nd	nd	nd	nd	3,83	nd	87,0	1,7	0,1
PA25208D	Cu green	SB-18	8,94	nd	14,1	0,27	nd	nd	nd	nd	0,03	nd	75,7	0,6	0,3
PA25209	Cu whitish	SB-07	3,87	nd	2,73	nd	nd	nd	nd	nd	0,08	0,0	93,0	0,2	0,1
PA25210	Cu blue	SB-17	22,1	nd	76,2	nd	0,15	nd	0,3	nd	0,14	0,8	nd	0,4	nd
PA25211	Cu blue and red	SB-17	22,4	nd	13,9	nd	0,05	nd	nd	nd	0,56	0,1	61,6	0,6	0,4
PA25212	Cu blue and red	SB-05	4,93	nd	9,73	nd	0,11	nd	nd	nd	0,01	nd	84,6	0,6	nd
PA25213	Cu green	SB-fondo	2,68	nd	96,2	nd	nd	nd	nd	nd	0,51	nd	nd	0,4	0,2
PA25213B	Cu green	SB-fondo	6,67	nd	90,3	nd	nd	nd	0,1	nd	1,29	0,2	nd	0,6	0,8
PA25214	Cu blue	SB-fondo	15,6	nd	17	0,16	nd	nd	nd	nd	0,46	0,1	66,1	0,4	0,1
PA25214B	Cu chalcopyrite	SB-fondo	42,5	nd	54,2	0,62	nd	nd	nd	nd	1,19	0,3	nd	0,5	0,2
PA25215	Cu light green	SB-fondo	2,38	nd	97,5	nd	0,04	nd	nd	nd	0,08	nd	nd	nd	nd
PA25329	Copper	SUP.	9,64	nd	2,74	0,04	nd	nd	nd	nd	0,03	nd	86,9	nd	0,6
PA25329B	Copper	SUP.	9,33	nd	2,59	0,04	0,01	nd	nd	nd	0,03	nd	87,3	nd	0,75
PA25330	Copper	SUP.	15,3	nd	6,72	0,1	0,02	nd	nd	nd	0,01	nd	77,0	nd	0,79
PA25331	Copper	SUP.	9,73	nd	19,2	0,11	0,02	nd	nd	nd	0,08	nd	69,9	nd	1,04
PA25331B	Copper	SUP.	7,68	nd	15,2	0,08	nd	nd	nd	nd	0,38	0,17	75,2	nd	1,1
PA25332	Copper	SUP.	7,46	nd	38,6	0,16	nd	nd	nd	nd	0,2	nd	53,4	nd	nd
PA25332B	Copper	SUP.	7,43	nd	37,7	0,14	0,02	nd	nd	nd	0,16	nd	54,3	nd	nd

Table 3. Solana del Bepo lead isotope analysis

Reference	206Pb/204Pb	207Pb/204Pb	208Pb/204Pb	207Pb/206Pb	208Pb/206Pb
PA20275	18,487	15,68	38,677	0,84819	2,0921
PA23797	18,5066	15,6928	38,7527	0,84796	2,09400
PA23798	18,4883	15,6901	38,7451	0,84865	2,09565
PA25229	18,5757	15,6885	38,7760	0,84457	2,08746
PA25230	18,5209	15,6936	38,7672	0,84735	2,09316
PA25231	18,4985	15,6895	38,7284	0,84815	2,09360
PA25203	18,5281	15,6932	38,7842	0,84699	2,09327
PA25204	18,5154	15,6937	38,7755	0,84761	2,09423
PA25205	18,4722	15,6906	38,7106	0,84942	2,09562
PA25206	18,5201	15,6908	38,7618	0,84723	2,09295
PA25207	18,5062	15,6954	38,7713	0,84811	2,09504
PA25209	18,4847	15,6934	38,7351	0,84900	2,09552
PA25210	18,4283	15,6921	38,6459	0,85152	2,09709
PA25211	18,4879	15,6936	38,7524	0,84886	2,09609
PA25212	18,4628	15,6917	38,6801	0,84991	2,09503
PA25213	18,4786	15,6916	38,7186	0,84918	2,09532
PA25214	18,3945	15,6892	38,5954	0,85293	2,09821
PA25215	18,4742	15,6918	38,7187	0,84939	2,09583

5. THE WORKING TOOLS

During the archaeological excavation undertaken in 2016, a macrolithic assemblage consisting of 19 items was collected, including twelve picks, one percussor, one clast and five preforms. Apart from two of the preforms that belong to artefactual items of an undetermined nature, the rest of the examples are directly or indirectly related to the production and use of mining tools for ore extraction. These finds have been inventoried on a macroscopic level following a standardised analysis protocol designed specifically for the study of macrolithic assemblages (Risch, 2002: 35-48; Delgado-Raack, 2013: 187-199). The results deriving from this study add to those obtained for the stone artefacts collected by Vilaseca at the same archaeological site during the 1940s and 50s (Delgado-Raack and Gómez-Gras, 2017; Delgado- Raack and Soriano, 2017). The main raw materials are granitic rocks such as granodioritic porphyrys, quartz-dioritic porphyrys and granodiorites, as well as rocks affected to a greater or lesser extent by contact metamorphism (Table 4). In the absence of a more detailed thin-section petrographic analysis, we can advance here that among these latest lithologies there are rocks with diverse degrees of metamorphism ranging from sandstone to hornfels and including mottled, nodulous and cornubianitic slates.

Among the artefacts linked to the production and use of mining picks, we recorded intact raw material destined for the manufacture of picks; pick preforms in various degrees of preparation; picks in various states of use; discarded picks; and a tool probably destined for the transformation of picks. Among them a fragment of a rock clast affected by contact metamorphism that must have been transported to the archaeological site from the Prades River with the intention of using it as a support for the manufacture of picks (BEP-2016-14; Figure 11). Likewise, three pick preforms were recognised among the studied finds. One of them constitutes a flattened edge in an incipient state of transformation, given that it only has part of the perimeter carved bifacially (BEP-2016-9). Both the morphology and the lithology coincide with those of the picks and lead us to believe that it is a preform for this type of artefact. The two remaining preforms are undoubtedly picks (BEP-2016-3 and -17) with unused active surfaces. They have been rough cut to a pointed shape, but would have been too fragile for percussion, as they still have a large number of angles. At the same time, of particular note in both cases is the installation of partially prepared haft fittings consisting of indented notches (BEP-2016-3) or a very superficial cross-shaped groove located on the reverse and part of the left face (BEP-2016-17). These examples suggest that during the pick-making process no specific priority was given to any particular element and that possibly the haft fitting and the active surface were worked on gradually and alternately[2].

Table 4. Artefactual types and raw materials used to produce the macrolithic assemblage found at Solana del Bepo during the 2016 excavations

Artefacts:	Pick	Percussor	Pick-Preform	Pebble	Undeterminate-Preform	Total
	12	1	3	1	2	19
Lithology:						
Granitic rocks	7		1			8
Rocks affected by contact metamorphism	4		2	1	1	8
Limestone					1	1
Sandstone	1					1
Flint		1				1

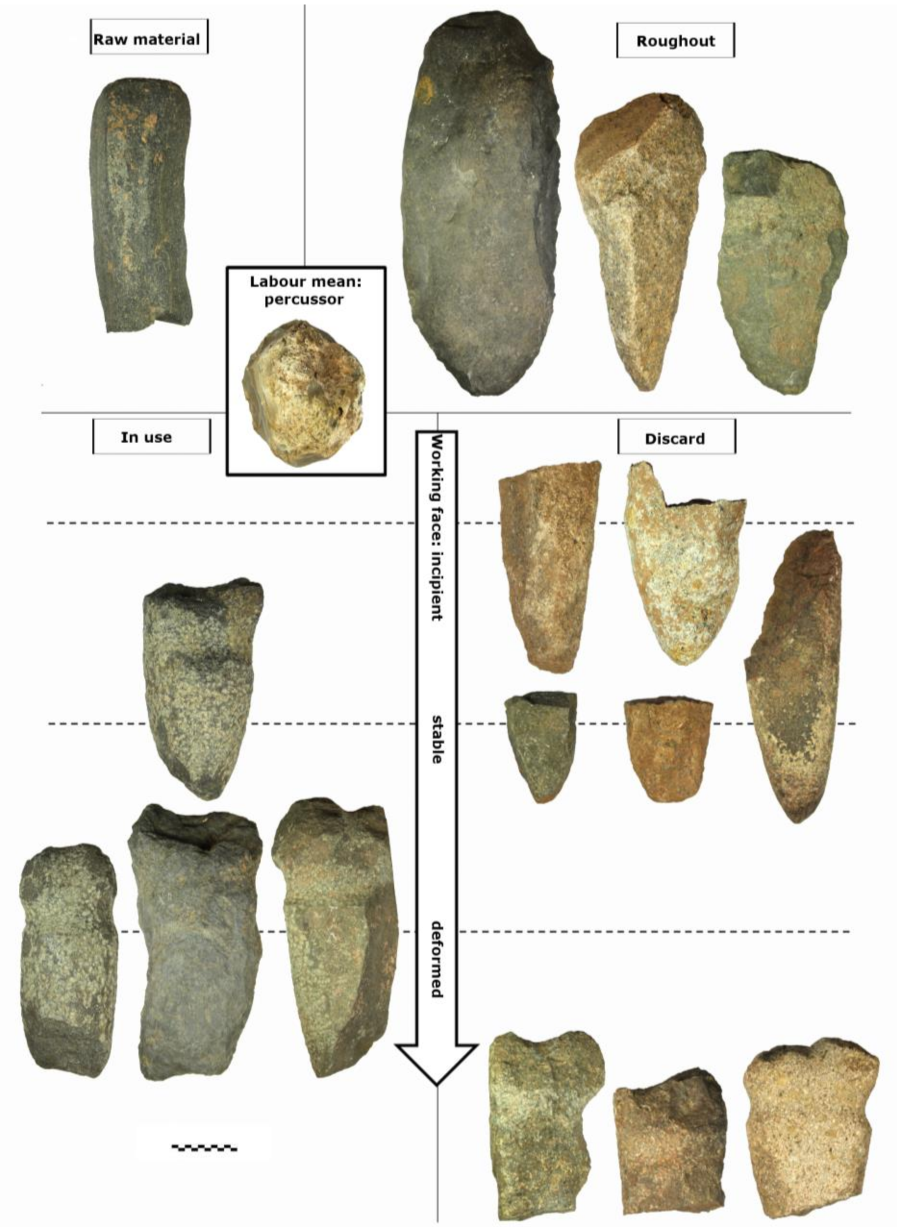

Figure 11. Scheme for the technological organisation of the items of the 2016 campaign that are related to the production and use of mining picks (from top to bottom and from left to right): BEP-2016-14, BEP2016-13 (percussor), BEP-2016-9, BEP-2016-17, BEP-2016-3, BEP-2016-6, BEP-2016-11, BEP-2016-18, BEP-2016-7, BEP-2016-12, BEP-2016-16, BEP-2016-10, BEP-2016-1, BEP-2016-19, BEP-2016-5, BEP-2016-2, BEP-2016-4.

In addition to the raw material and preforms, we found several used picks in three diverse states of wear. Among the slightly worn examples, with evidence of small pits and perpendicular extractions in the direction of the impact, there are only two fractured distal ends that were discarded where they were being used (BEP-2016-6 and BEP-2016-11). A second group is represented by picks that were operative or in use. Their active surfaces are clearly worn (levelled, striated and polished), but mechanically stabilised, as they do not present extractions. Among them there are three distal ends that were fractured accidentally in this phase of use and abandoned (BEP-2016-7, BEP-2016-12, BEP-2016-16), as well as a complete pick (BEP-2016-18). The third group of worn picks consists of examples that have lost their original morphology due to the detachment of large chips and flakes during the strong impacts against the contact material that caused the deformation of the piece (BEP-2016-1, BEP-2016-10, BEP-2016-19). Although these picks could have continued in use for a certain time, especially as they still had vertices on their active surfaces, it would soon have been necessary to repair them by pecking (and polishing?), to prevent a massive loss of stone and the complete exhaustion of the artefact.

Finally, we have defined a group of examples interpreted as castoffs as they are proximal ends, meaning that we are unable to establish when the accident in which they were fractured occurred (BEP-2016-2, BEP-2016-4, BEP-2016-5). Pick BEP-2016-5 is the example that was found with the adhered and dated charcoal. This piece is also the only one in the studied assemblage that presents clear signs of thermo-alteration in the form of dark colouring with craquelure around the perimetral groove. It should also be added that our attempts to remount the studied pieces did not allow any refitting.

In addition to the tools used for mining the ore, we found a tool that was probably used for pick production, either in their manufacture or repair in situ. It is a flint nodule in the size of a fist with a facet covered with small percussion pits on its most protruding edge (BEP-2016-13). It is possible that this nodule had been previously used as a flake extraction nucleus, judging by the negatives that cover a large part of its surface.

The assemblage of macrolithic items is completed by a limestone cobble with various radial extractions on the obverse (BEP-2016-8) and a fragment of another hornfels cobble that has lost its bottom half and back (BEP-2016-15). In the latter case, the fracture plane on the reverse was evened out by friction to make an artefact, probably not a pick, judging by its lack of thickness.

Nevertheless, the macroscopic study of the macrolithic assemblage presented here has allowed us to define production activities involving mining picks as the predominant artefactual category in the context. They were manufactured, used and abandoned in situ. With respect to the results of the study of Vilaseca's collection, it was not possible to observe some of the stages in the useful life of those artefacts. However, we were able to better define the diverse states of wear especially of the active surfaces.

6. DISCUSSION AND CONCLUSION: SOLANA DEL BEPO IN THE CONTEXT OF MINING ON THE IBERIAN PENINSULA

Mining at Solana del Bepo appears to complement chronologically that carried out at Mina de la Turquesa and probably Barranc Fondo, both in the neighbouring locality of Cornudella de Montsant (Montero-Ruíz *et al.*, 2012; Soriano *et al.*, 2017; Rafel Fontanals *et al.* 2018). The identification through lead isotope analysis of the probable exploitation of both mines during the Chalcolithic, by their coincidence with the finds from Coveta de l'Heura, was a surprise, in so much as that archaeological site is geographically much closer to Solana del Bepo than the other two mines. The arsenical copper awl was consistent with Mina de la Turquesa, the only mine in the area with ore capable of producing arsenical coppers, whereas the metallurgical remains, among them a reduction vessel, and ores without arsenic fit the isotopic field of Barranc Fondo, whose copper ores have similar purity characteristics to those of Solana del Bepo (Rafel *et al.*, 2016).

The new series of lead isotope analysis better define the Solana del Bepo isotopic field, but there is still an overlap area between the mines (Figure 12). Solana del Bepo, Barranc Fondo and Els Crossos (this latter at the nearby municipality of Alforja) all present a lineal distribution with the main variation being the proportion of the 208Pb/204Pb ratio and the highest values being those from Solana del Bepo. Mina de la Turquesa differs from the previous pattern and its ores present a very broad isotopic field and radiogenic values, but with values in the 206Pb/204Pb ratio that are always higher than at the other mines.

The isotopic field that defines the 18 samples from Solana del Bepo overlaps in part the field defined for Barranc Fondo in Cornudella and covers part of the distribution of the copper ores studied from Coveta de l'Heura that were previously attributed to this mine. However figure 16, with isotope ratios of 208Pb, shows us how the samples from Coveta de l'Heura completely match the Barranco Fondo, and overlaps only a marginal area of the Solana del Bepo. In other words, the distribution of LIA from Coveta de l'Heura ores clearly falls out of the main area of the Solana del Bepo samples. Discrimination based on elemental composition is not possible, as both mines present coppers with low levels of impurities like the ores from Coveta de l'Heura. The detection of small quantities of Zn, Pb, As, Sn or Bi in some of the samples merely confirms that they have a similar mineralogy. In this case, the limitation of samples from Barranc Fondo allows a better definition of its isotopic field, although Figure 12, with isotope ratios of 208Pb, shows us how the samples from Coveta de l'Heura are closer in their distribution to Barranc Fondo than to Solana del Bepo, as in that case they are the samples most distanced from the main concentration that open up its field and overlap with the other mineralisations. Although it is not possible to completely rule out a certain link with some of the ores from Coveta de l'Heura, the Solana del Bepo radiocarbon dates would support the idea that no mining was carried out during that period of the Chalcolithic.

Of the collection of prehistoric objects from the north-eastern Iberian Peninsula subjected to lead isotope analysis so far, only three show a possible coincidence with Solana del Bepo. However, of these three cases only the three-rivetted bronze dagger from Cova de la Font Major (Espluga de Francolí) can be linked with a certain probability to ores from Solana del Bepo. The other two pieces are the flat Chalcolithic axes from Cave M at Cingle Blanc (Arbolí) that, in addition to containing arsenic, fall outside the isotopic field of Solana del Bepo in some ratios. The dagger from Cova de la Font Major has been dated to the end of the Early Bronze Age, both typologically and for its correspondence with a C^{14}-dated dagger mould matrix (Soriano and Amorós 2014). This dagger was used as a reference to define the exploitation chronology of Solana del Bepo (Rafel and Soriano, 2017b), a hypothesis now confirmed by the C^{14} dates obtained. Of the finds with an imprecise chronology in the Chalcolithic - Early- to Middle-Bronze Age, the reduction vessel from Balma del Duc (Montblanc) has been linked to Mina de la Turquesa, while the copper arrowhead found out of context in Marçà is associated with a mine in the Lower Priorat (perhaps Linda Mariquita) (Montero, 2017), that also contains arsenic, like the vast majority of the metal objects analysed for these periods. This opens up the possibility that different mines were supplying raw material simultaneously.

We have very few finds belonging to the Early- to Middle-Bronze Age, as research efforts to date have focused largely on the Chalcolithic. Of them, only a laminar fragment from the settlement of El Molló (Móra la Nova) could fit in with the Solana del Bepo mineralisation (Piera *et al.*, 2016: 97-98). This laminar fragment is also of bronze and if this origin is confirmed, it would add weight to the chronology of the first half of the second millennium cal BCE for the exploitation of Solana del Bepo. This period of the Bronze Age is characterised on the Iberian Peninsula by the regionalised use of mineral resources, with different lead isotope distributions in the finds from the north-east and the south-east and the Argar culture, or on the Central Plateau around the Madrid region, which are the most researched areas to date (Montero, in press). It is only from the second half of the second millennium BCE, and above all during the Late Bronze Age, that we detect an increase in the circulation of metal, probably also coinciding with an increase in production. Continuing in use at that time were the Astur-Leonese mines of El Áramo (Blas Cortina, 2005) and El Milagro (Blas Cortina, 2007-2008) and probably the José Palacios mine in Linares, due to the isotopic coincidence of Argaric finds from the more advanced phases, although the known dating places it at the end of the third millennium cal BCE (Arboledas *et al.*, 2015). In addition, according to C^{14} dating, mining began at Sa Mitja Lluna in Menorca (Hunt Ortiz *et al.*, 2014). Geographically, Solana del Bepo completes this regionalised mining production, although these were not necessarily the only mines exploited in each of the mentioned regions.

We need to carry out more lead isotope analyses of Bronze Age finds in the north-eastern Iberian Peninsula, a time in which tin alloys predominated. This will allow us to determine the scope and intensity of the metal production obtained with ores from Solana del Bepo and to identify other possible prehistoric mines that will help explain some of the metal objects that still do not coincide isotopically with the available data.

For the moment, the new chronological and analytical data from the Solana del Bepo mine complete the panorama known to date of prehistoric metallurgy in the northeast of the Iberian Peninsula. This constitutes an important advance for the study of copper mining in a region that until recently was practically unexplored in this sense.

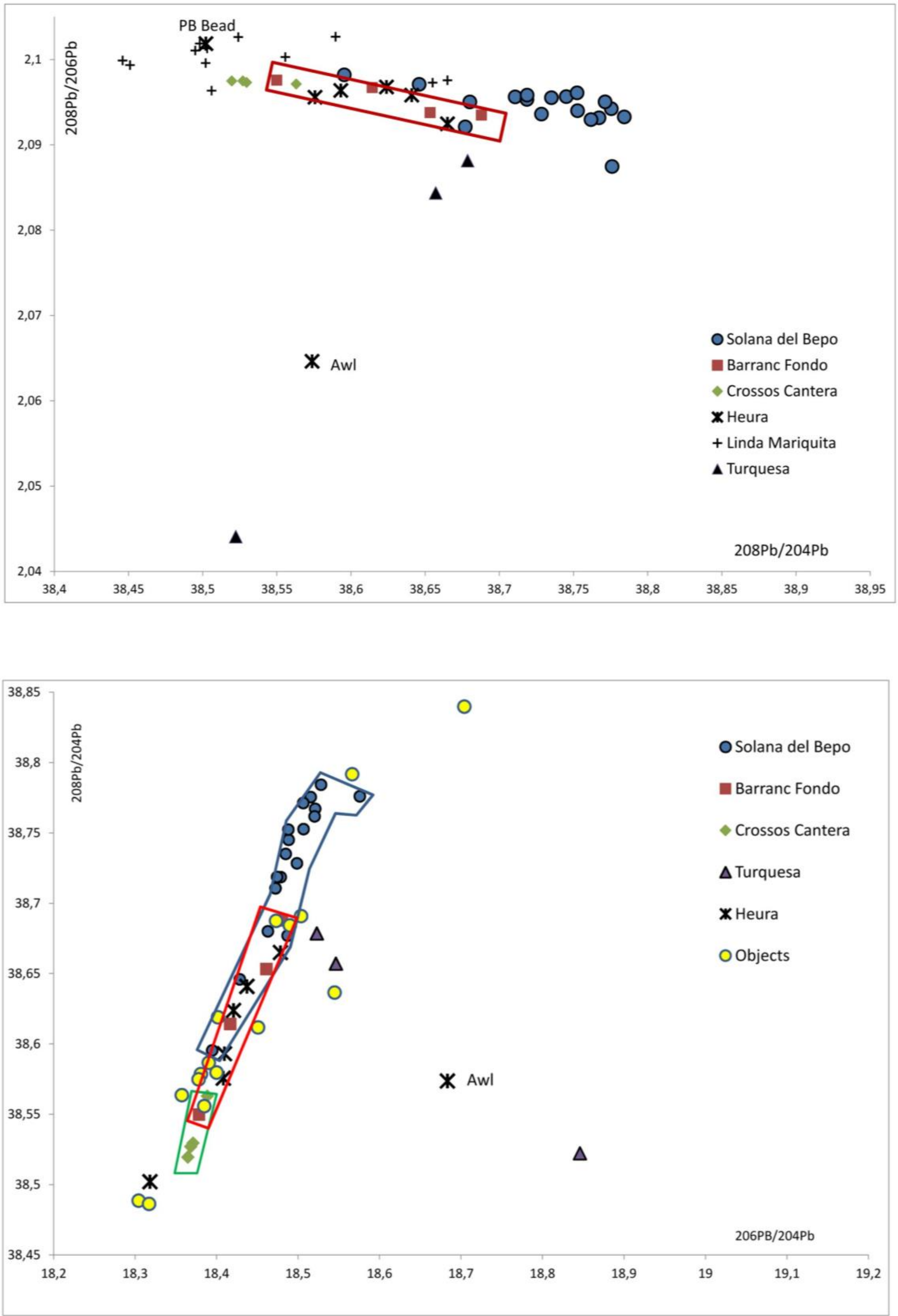

Figure 12. Comparative results of LIA ratios of copper ores from Solana del Bepo and other mines in the region with archaeological items (Coveta de l'Heura and Chalcolithic and Early Bronze Age objects from the same geographical region) and comparative results of copper ores from Solana del Bepo and other mines in the region with archaeological items from Coveta de l´Heura.

ACKNOWLEDGEMENTS

To the financiers of the projects "Mineral and metal resources, exchange and trade in prehistory and protohistory on the Iberian Peninsula (Catalonia and the north of the Valencian Country)" of the Spanish Government's Ministry of Economy and Competitiveness (HAR2014-54012-P) and "Mining and Metallurgy in southern Catalonia: from prehistory to the mediaeval period" of the Regional Government of Catalonia, who have made this study possible. The authors also wish to express their gratitude for the technical and human support received from the SGIker of the UPV/EHU and the European financing (FEDER and ESF) and the X-ray Laboratory at the CENIM-CSIC.

To the geologists Joan Carles Melgarejo and Josep Mª Mata-Perelló for their geological evaluations. To Josep Carreras for his help in locating the vein prior to the excavation. To Sílvia Vila (UdL) for her kind cooperation in the anthracological identification of the carbonised wood. To Rosa Mª Mercado for her assistance during the fieldwork.

To Jaume Massó, director of the Salvador Vilaseca Archaeological Museum of Reus, who has consistently placed at our disposal all the means available to him to assist us with our research.

And to the *Research Group in Mediterranean Social Archaeoecology* (ASOME-UAB) for making it possible to study the lithic materials by placing at our disposal the necessary technical resources.

NOTES

[1] The analyses to ascertain the composition of the metal were carried out using the X-ray fluorescence technique with the National Archaeological Museum's INNOV-X Alpha spectrometer equipped with an X-ray tube, silver anode, working conditions: 35kV, 20µA. The acquisition times were set at 40 s and the quantitative values were calculated based on a calibration validated with certified guidelines. The analysis is expressed as a percentage in weight (%) of each of the detected elements in Table 2 (nd = not detected). In the case of the silver (Ag) and antimony (Sb), the detection limit was 0.15 % and for the rest of the elements it was 0.02 %. The margins of error in the measurements were around 1% for the majority elements, between 2% and 5% for the minority elements, and as much as 40% for the elements with a composition lower than 0.1%. LE= light elements (atomic number < 20). The fundamental parameter (FP) calibration was adjusted on the basis of the analyses of a set of 18 different metal and copper-based alloy standards (including arsenical copper).

[2] In the study carried out on the picks from the Vilaseca collection, only two preforms were recorded that present slight carving on the flanks of the active surfaces and no evidence of hafting (BEP-4275-4 and BEP-4275-5). These would be preforms immediately prior to BEP-2016-3 and BEP-2016-17 (Delgado-Raack and Gómez-Gras, 2017).

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