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Chalcolithic and Bronze Age Copper Mining at the Internal Betic Ranges (South-East of the Iberian Peninsula):

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Abstract: This paper reviews the early development of metallurgy in the south-eastern Iberian Peninsula, focusing on Chalcolithic and Bronze Age copper mining within the Internal Betic Ranges. Archaeological evidence documents metallurgical production during the Los Millares and El Argar cultures, despite the elusive identification of prehistoric copper mines in this region. Several surveys have been conducted from the 19th century to the present, uncovering limited yet significant archaeological evidence, such as stone tools and pottery around the mines, suggesting prehistoric mining activities. These studies usually include geological background, identifying copper mineralisation across three tectonic complexes: Nevado-Filábride, Alpujárride, and Maláguide. Recent investigations employ modern analytical methods, including trace element characterisation and lead isotope analysis (LIA), to connect archaeological finds with local copper sources. Key findings indicate that copper ores were processed at settlements rather than mines, highlighting the small-scale nature of early metallurgy in the region, in contrast to other mining regions such as Sierra Morena. Continued research is essential to fully understand the extent and chronology of copper mining activities throughout different historical periods in the Betic Ranges.

Keywords: Metallurgy, Survey, Recent Prehistory, Trace Element Compositions, Lead Isotope Analysis, Mining hammers, Stone Tools

Résumé : Cet article passe en revue les premiers développements de la métallurgie dans le sud-est de la péninsule Ibérique, en se concentrant sur l'exploitation minière du cuivre au Chalcolithique et à l'âge du Bronze dans les cordillères Bétiques internes. Si la production métallurgique au cours des cultures de Los Millares et d'El Argar, les mines de cuivre préhistoriques restent difficilement saisissables dans cette région. Plusieurs études ont été menées du XIXe siècle à nos jours, mettant au jour des preuves archéologiques limitées mais significatives telles que des outils en pierre et des poteries autour des mines, suggérant des activités minières préhistoriques. Ces études incluent généralement le contexte géologique, identifiant la minéralisation du cuivre dans trois complexes tectoniques : Nevado-Filábride, Alpujárride et Maláguide, et les prospections récentes emploient des méthodes analytiques modernes, notamment la caractérisation des éléments traces et l'analyse isotopique du plomb (LIA), pour relier les découvertes archéologiques aux sources de cuivre locales. Les principales conclusions indiquent que les minerais de cuivre étaient traités dans les villages plutôt que dans les mines. Cela souligne la faible envergure des premières productions métallurgiques dans la région, contrairement à d'autres régions minières telles que la Sierra Morena, et en particulier sa partie centrale, comme le démontrent les prospections et sondages en cours dans la vallée du Alto Guadiato et Los Pedroches. La poursuite des recherches est essentielle pour saisir l'ampleur et la chronologie des activités minières de cuivre au cours des différentes périodes historiques dans les cordillères Bétiques.

Mots clés : métallurgie, prospection, Préhistoire récente, compositions d'éléments traces, analyse isotopique du plomb, marteaux miniers, outils en pierre

The south-east of the Iberian Peninsula is a key region in the development of early metallurgy. Besides the debate on the possible independent invention of metallurgy during the 5th millennium BC based on the early chronology of Cerro Virtud, Almería (Ruiz Taboada and Montero-Ruiz, 1999; Montero-Ruiz et al., 2021), clear metallurgical production is documented during the Los Millares culture (Chalcolithic) and the El Argar culture (Early Bronze Age). Copper ores have been found in many Chalcolithic sites together with smelting crucibles, prills and fragments of slag. On the contrary, few melting crucibles or moulds from this period have been identified

in the archaeological record (Montero-Ruiz, 1992). A significant number of metal objects are documented, mainly in the Bell Beaker period, with simple shapes (awl, dagger, axe, arrowhead) but personal ornaments made of copper are absent in this area and in the whole Iberian Peninsula (Murillo-Barroso and Montero-Ruiz, 2012). The technology of this metallurgy based on secondary copper ores has been described in detail in some papers (Rovira-Llorens and Montero-Ruiz, 2013, Murillo-Barroso et al., 2017; 2025b). The main features are:

– direct reduction of ores without the addition of fluxes, using ceramic vessels (smelting crucibles) as containers for both the ores and the fuel required for the smelting process;

– use of polymetallic ores, especially those containing arsenic, which naturally produced arsenical copper;

– the small amount of slag produced is immature, with very heterogeneous mineralogical and chemical compositions and high viscosity, therefore resulting in an inefficient separation of metallic copper, with substantial copper losses in the slag;

– thermodynamic equilibrium and atmosphere stability were not consistently maintained, with variable $_pO_2$ and redox conditions both locally and temporarily, with better reducing conditions in some areas of the crucible at certain moments and more oxidising conditions at some others.

During the Early Bronze Age (El Argar culture), there were no substantial technological changes, although evidence of smelting activities and copper ores is sparser in the main settlements, with a better record of moulds and crucibles (Montero-Ruiz and Murillo-Barroso, 2010). Metal production seems to have increased, as evidenced by the higher number of metal objects, with some typological changes: the use of rivets in daggers instead of tangs, the presence of wings in arrowheads, the first appearance of weapons (halberds and swords) as well as the proliferation of personal ornaments (spiral rings, earrings, bracelets, ear dilators and exceptionally, silver diadems), which were almost absent from the archaeological record during the Copper Age.

Although some evidence suggests local or regional production, the identification of the copper mines worked at this time is very elusive. This contrasts sharply with other regions of Iberia where prehistoric copper mines are well documented (Blas Cortina and Suárez Fernández, 2022; Rovira Llorens and Montero-Ruiz, 2022). However, in these areas, smelting and melting activities, along with the related materials, are nearly unknown, for example in the astur-leones region in the north of Iberia. The exception is the Iberian southwest, where both mines and metallurgical-related materials have been found (Hunt Ortiz, 2003).

GEOLOGICAL BACKGROUND

The Betic Cordillera constitutes the westernmost end of the Mediterranean Alpine Orogen and consists of two major domains: the External and Internal Zones (fig. 1).

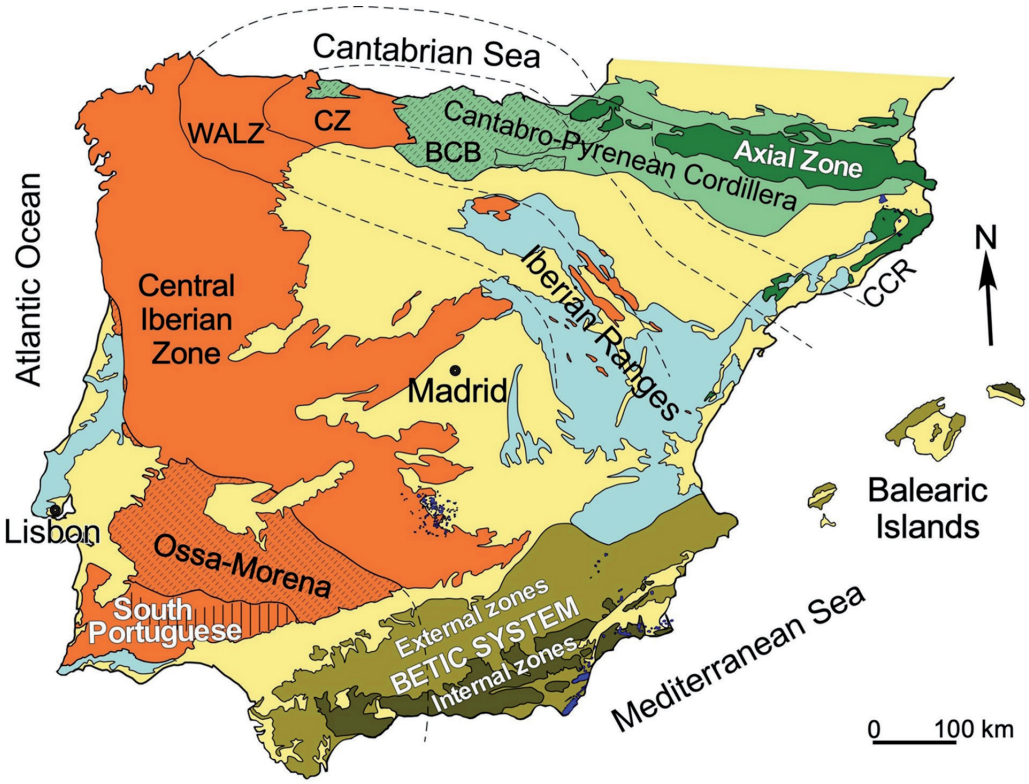

Fig. 1 – Geological map sketch of the Iberian Peninsula.

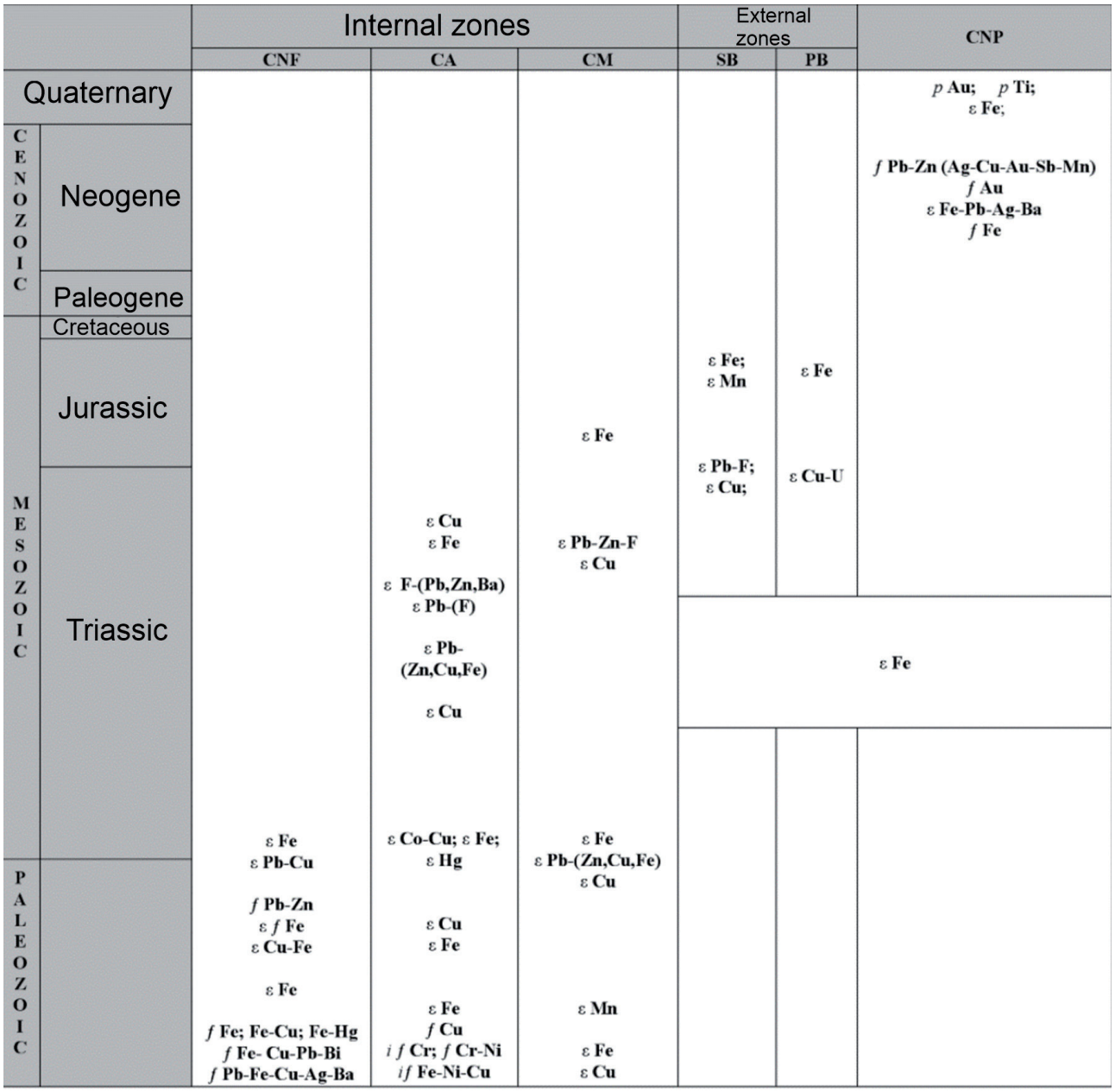

Fig. 2 – Main mineralization zones in the units of the Betic Chain (modified from García-Cortés, 2011). CNF = Nevado-Filábride Complex; CA = Alpujárride Complex; CM = Maláguide Complex; SB = Subbetic; PB = Prebetic; CNP = Postorogenic Neogene Basins.

The External Zones are mainly composed of Mesozoic and Tertiary sedimentary rocks, deposited along the southern paleomargin of the Variscan Iberian Massif. The Internal Zones are mainly made up of metamorphic Paleozoic and Mesozoic rocks, distributed across three superposed tectonic complexes: from bottom to top, the Nevado-Filábride, Alpujárride and Maláguide complexes. These Internal Zones extend over more than 600 km from the Málaga province to the south of Alicante, covering the provinces of Almería and Granada, with several mountain ranges in both the coastal and inland areas. Copper is present in all three domains, as described by J. Sánchez-Valverde et al. (2013) and A. García Cortes (2011; see fig. 2):

– *Nevado-Filábride Complex.* Copper mineralisations are found within the so-called Mulhacén section, in low-temperature, hydrothermal veins and fractures. The main primary ores include siderite, with disseminations of galena, pyrite, chalcopyrite, sphalerite, cinnabar, stibnite, tetrahedrite and arsenopyrite.

– *Alpujárride Complex.* Two types of copper mineralisation appear within the metasedimentary formations of this complex: stratiform-stratabound Fe-Pb-Zn-Cu deposits of probable sedimentary origin, and subvolcanic deposits with a similar chemistry, filling faults and/or fractures, probably remobilising the former stratiform mineralisation. The copper minerals are predominantly sulphides, and minor copper carbonates as secondary

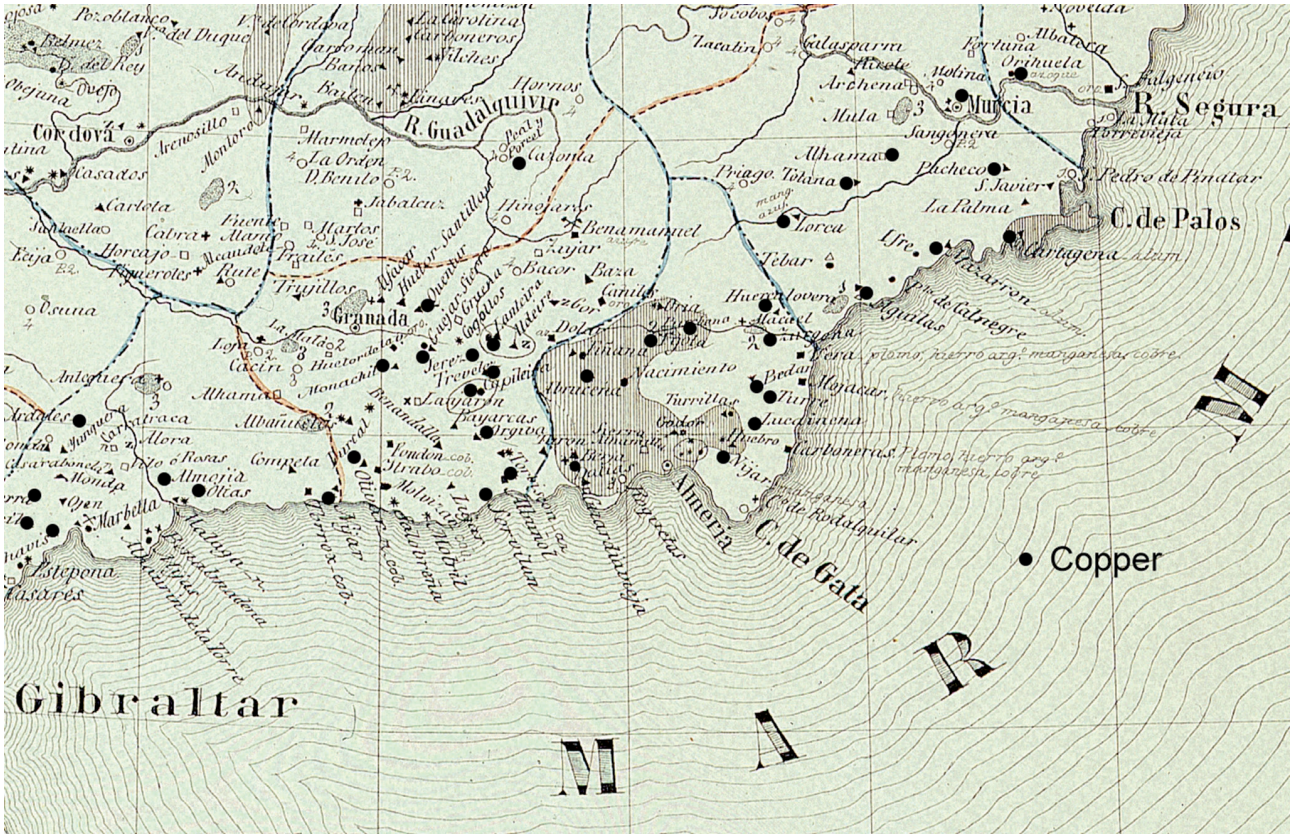

Fig 3 – Fragment of the "mapa minero" of Miguel Avellana (1860) showing the distribution of copper mines in the Betic Ranges (https://www.ign.es/web/catalogo-cartoteca/resources/html/003492.html).

mineral associations, alongside tyrolite, annabergite, cinnabar, goethite, magnetite, proustite and pyrargyrite.

– *Maláguide Complex.* Located in the western part of the region, near the city of Málaga and in the Montes de Málaga, with some outcrops also located north of Granada and in the Sierra de las Estancias. In this complex, copper mineralisation mainly occurs in the Saladilla Formation, which consists of conglomerates, sandstones, pelites, grey dolomites and Permian-Triassic gypsum. Copper minerals in the Maláguide Complex are mostly sulphides. Minor secondary copper carbonates, likely associated with basic volcanism, appear particularly in the Sierra Arana. In the Sierra de las Estancias area, the copper mineralisation appears to be of sedimentary origin, although recent tectonics activity has played an important role in its final concentration (Carrasco Cantos et al., 1979).

Historical studies mention the use of some copper mines since the 16th century (González, 1832) and geological and mineralogical studies have documented various types of copper ores and associated mineral species (Calderón, 1910; Calvo, 2015). Copper mines are also represented on historical maps (fig. 3).

Modern and interactive resources, such as MINDAT website (https://www.mindat.org/loc-3102.html), provide precise information on mines, including descriptions and locations for each province. Other valuable tools include the layer with mines location launched by the Spanish Mining Institute (Instituto Geológico y Minero de España, IGME-CSIC), the maps available through the Spanish Infrastructure of Spatial Data Geoportal (IDEE), which can be downloaded for use in GIS software, or the official app developed by the National Geographic Institute (Instituto Geofráfico Nacional, IGN). These resources are useful when planning field surveys.

LOOKING FOR PREHISTORIC MINES

The archaeological research in the 19th century began with the Siret brothers (Siret and Siret, 1890), mining engineers working in the mining districts of Almería and Murcia. Luis Siret, who lived in Herrerías (Almería) until his death in 1934, documented the archaeological discoveries made in these mines and had access to materials found during the mining operations. However, this modern mining was mostly focused on lead and iron. Only a few references to Roman or medieval materials were published (Siret, 1906), but general comments on the use of copper in the early metallurgical stages can be found in their first book (Siret and Siret, 1890, p. 65, 271). They proposed the local exploitation of some ore deposits close to archaeological sites, such as Parazuelos (Murcia), based on the similar elemental composition of slag fragments recovered at the site and the copper ores collected from the surrounding mines (fig. 4).

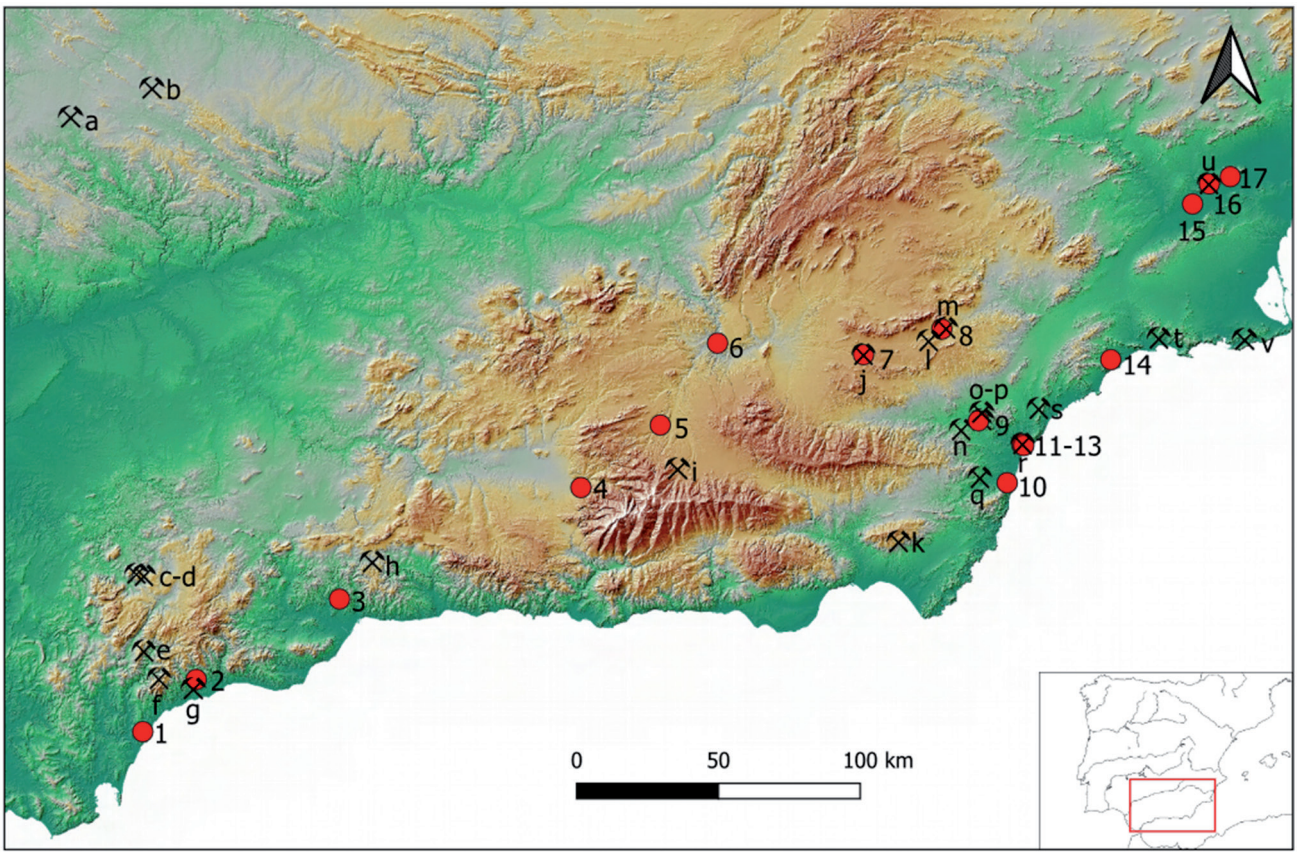

Fig. 4 – Location of archaeological sites and mines mentioned in the text. Settlements – 1: Castillejos de Alcorrín; 2: Montemayor; 3: Cerro de la Peluca; 4: Cerro de la Encina; 5: Cuesta del Negro; 6: Terrera del Reloj; 7: El Malagón; 8: Cerro de los López; 9: Santa Bárbara; 10: Las Pilas; 11: Cerro Virtud; 12: Herrerías; 13: Almizaraque; 14: Parazuelos ; 15: Monteagudo; 16: Cerro de la Mina; 17: San Antón. Mines – a : Las Minillas; b: Los Perules;, c: Escaurías; d: Montecortillo; e: La Horadada; f : San Pedro; g: Cadernillo; h: Mina Casacara; i: Santa Constanza; j: El Malagón; k: ALS 2; l: Peñón Colorado; m: Cerro de las Minas; n: Zurgena ; o: Cerro Minado; p: Molino del Judío; q: Pinar de Bédar; r: Herrerías ; s: Pulpí; t: Balsicas ; u: Cerro de la Mina; v: Filón Consuelo.

Despite L. Siret's knowledge of the mining activity in the region, only one hammerstone is found in the Siret collection at the Museo Arqueológico Nacional (MAN) in Madrid. It is a rectangular-shaped, partially grooved cobble stone found at the 'Niño' mining concession (fig. 5), located near the Herrerias hill (Murillo-Barroso et al., 2020, p. 94, fig. 6). While it is not the typical grooved hammerstone found in many other prehistoric mines in Iberia or Europe, S. Timberlake (2023) notes that such cobbles with minimal modifications are very common in many sites in Britain, but are difficult to identify in the field and are occasionally not recognized as such.

Surveys in the 1980s and 1990s

In the 1980s, surveys linked to the Millares project identified some copper deposits (20 mines) around the archaeological site, but no archaeological materials (such as stone tools or pottery) were associated with any of these mineralisations, which were potentially the most suitable for exploitation (Keesman et al., 1991–1992, p. 290). However, a brief note on a possible Chalcolithic copper mine in Sierra Alhamilla (Site ALS2) was published (Rothemberg et al., 1988).

The archaeological record (handmade pottery fragments with some copper ores and slags) was not diagnostic, and no further references to this site have been published since then, except for the presence of arsenic in the copper ores that could be related with the arsenical copper production (Rothemberg, 1989). Also, near the El Malagón site (Granada), a small copper vein was identified, leading to the suggestion that the location of the Chalcolithic site was determined by this resource. However, no tools or data on the composition of the copper ore were published to confirm the similarity with the mineral found in the settlement (Arribas et al., 1989).

Cl. Domergue (1987; 1990) made brief references in the 'Corpus of Roman mines in the Iberian Peninsula' to prehistoric tools found at Filón Consuelo and Cerro Minado (a single hammer, though without a precise description or documentation).

The Vera Basin (Almería) was selected by Montero-Ruiz for his PhD on prehistoric mining and metallurgy (Montero-Ruiz, 1992). Some copper mines were sampled, including Cerro Minado and Pinar de Bedar, with ores characterised by XRF. No evidence of prehistoric tools was found. The copper ores usually contained high levels of arsenic and some other minor elements in proportions similar to the archaeological ores found in the Almizaraque metallurgical site (Montero-Ruiz, 1992). This suggested that arsenic might have been a natural

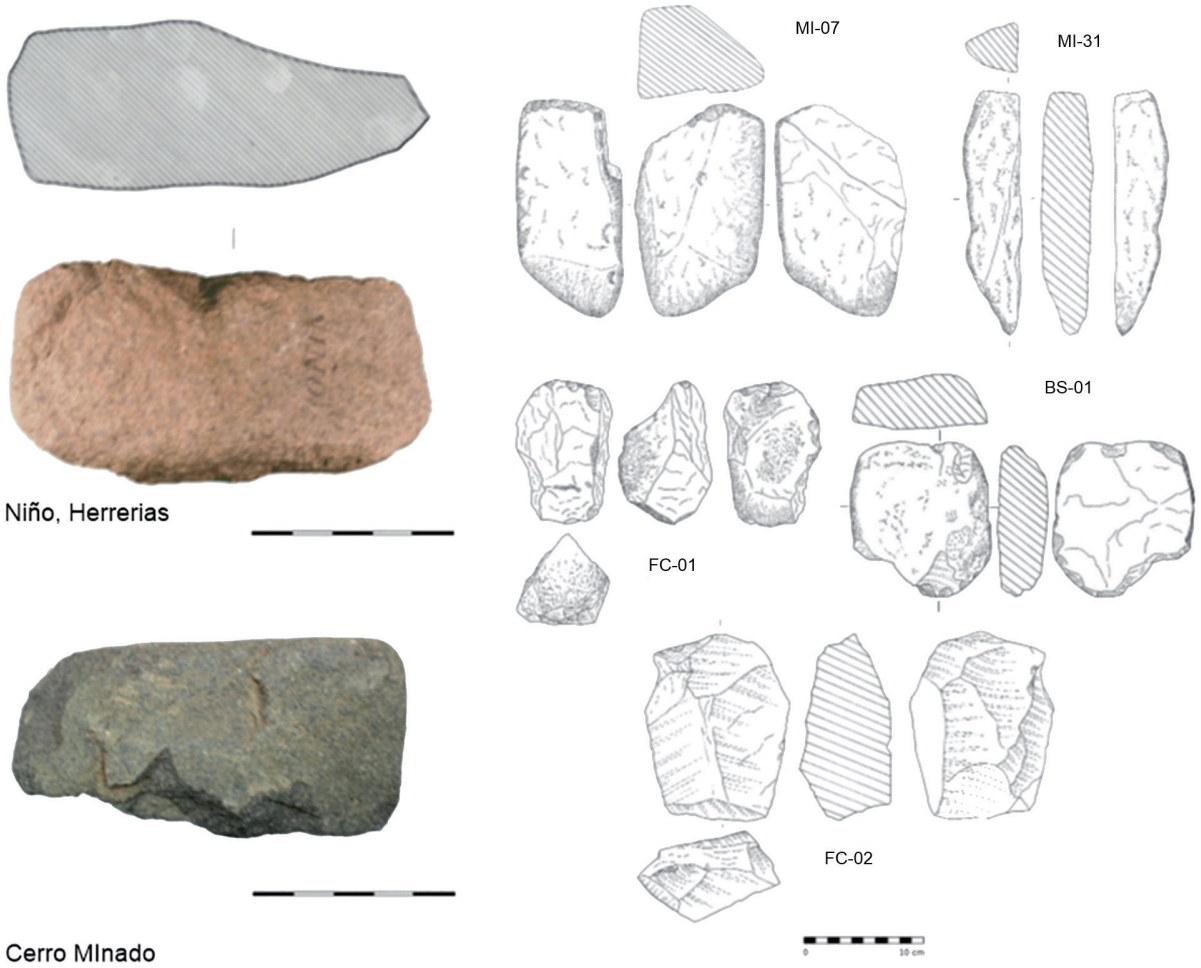

Fig.5 – Stone tools from Niño, Herrerías (after Murillo-Barroso et al., 2020) and Cerro Minado, Balsicas, and Filón Consuelo (after Escanilla, 2016).

alloy, and its presence in the metal would have depended on the original ore smelted.

At the same time, Rodríguez Vinceiro started a survey in Málaga Province, visiting copper mines and sampling ores (Rodríguez Vinceiro et al., 1992). This research highlighted the absence of mines from this province in Domergue's Roman mines catalogue (Domergue, 1987). Rodríguez Vinceiro's paper compiled several references to stone hammers and provided information about three copper mines near Chalcolithic sites with metallurgical evidence. Stone tools or prehistoric pottery suggesting prehistoric mining activities were not found at these mines; instead, the proximity to archaeological sites was the main argument used to suggest their exploitation during this period.

Years later, F. Rodríguez Vinceiro published new information on the mines in Málaga province, with elemental composition analyses of ores and a few lead isotope data (Rodríguez Vinceiro et al., 2018). The absence of modern works in the likely ancient small trenches and the recovery of lithic tools related to ore crushing at the Casacara mine are significant. Fragments of stone hammers and prehistoric pottery were also mentioned at the La Peluca mine, located very close to the Cerro de La Peluca settlement. The paper also includes new references to mines with stone tools made of diabase, although the original information and tool descriptions remain unpublished (Rodríguez Vinceiro et al., 2018, p. 95). The limited number of lead isotope analysis (LIA) of local ores could only suggest the use of the Casacara mine, but this evidence requires further reinforcement through more comprehensive isotopic characterisation.

Prehistoric Mining in coastal areas of Murcia and Almería

The next survey was conducted in the province of Murcia by N. Escanilla as part of his PhD (Escanilla, 2016). Several units were visited to identify the mining works and sample the copper ores, including: Sierra de Orihuela, Sierra Espuña, Sierra de la Tercia, Sierra de la Torrecilla, Sierra de En Medio, Sierra de Almagro, Sierra Almenara, Sierra del Águila, Sierra de la Carrasquilla, Sierra del Aguilón, Loma de Bas, Sierra de las Moreras, Sierra del Algarrobo, Sierra de Cartagena and Sierra de Carrascoy.

For the first time, a direct radiocarbon date from a copper mine was published (Cerro Minado, MAMS-18508: 3905 ± 21; 2500–2300 cal. BC) with information on two other prehistoric mines (Filón Consuelo and Balsicas) in the area (Escanilla and Delgado-Raack, 2015). The few stone tools from Cerro Minado confirmed the references made by Cl. Domergue (1987) and other early 20th century sources regarding the discovery of antler tools (Escanilla, 2016, p. 208–209). All the stone tools from the three mines are similar (fig. 5), consisting of unmodified or minimally modified gabbro or amphibolite cobbles, without clear grooves to facilitate handling. However, grooved stones were found among the stone hammers in the Bronze Age sites of El Argar and Peñalosa. Therefore, the absence of grooves in the Cerro Minado mining tools, combined with the radiocarbon date obtained, is the main evidence supporting the classification of all of Cerro Minado's stone tools as belonging to the Chalcolithic period (Escanilla and Delgado-Raack, 2015, p. 94).

The survey provided mineralogical and trace element data using pXRF, PIXE and XRD from several mines, distinguishing some rich polymetallic mines with arsenic and other pure copper-iron ores.

German Survey around Castillejos de Alcorrín (Málaga)

This survey focused on the raw materials found in the hinterland of the Phoenician site of Castillejos de Alcorrín. Iron, copper and lead mines were visited and sampled (Renzi et al., 2016). Analyses by XRD and ICP-SFMS identified copper minerals in five mines:

1. San Pedro (chalcopyrite and brochantite, with significative detection of Co, Ni, Zn, As and Cr)
2. Cardenillo (chalcopyrite and brochantite, with Co and As as minor elements)
3. Montecortillo (malachite, atacamite and brochantite, with As, Pb and Co)
4. Las Escaurias (azurite, bornite and brochantite, Pb, Sb, W, As and Ag)
5. La Horadada (chalcopyrite)

Historical references suggest that mining activities began between the 16th and 18th centuries, and it is difficult to confirm earlier exploitation, except during Roman times. The lead isotope analysis (LIA) of archaeological material from the site of Los Castillejos does not match any of the LIA results obtained from geological samples. The proximity of some archaeological remains to the mines is insufficient to confirm the prehistoric use of these copper sources. Due to their visual proximity, the Bronze Age site of Montemayor is related to the Cardenillo mine. Furthermore, a stone hammer was discovered at Montemayor, although no prehistoric evidence comes from Cardenillo mine (Renzi et al., 2016, p. 169).

Lower Segura valley (Santomera, Murcia)

The Lower Segura Valley has received limited scholarly attention concerning prehistoric mining activities. There is, however, longstanding tentative evidence for the early exploitation of local copper resources. A survey conducted in 2010 and 2011 by D. Brandherm et al. (2014) at the Cerro de la Mina settlement identified a significant number of potential prehistoric ore-crushing tools in the form of metabasite cobbles. Natural erosion and modern mining activities have likely destroyed parts of the archaeological site. Cerro de la Mina is notable for its deposits of copper oxide ore, primarily malachite. Modern extraction activities are evidenced by spoil heaps scattered along the lower slopes of the hill.

More than 500 metabasite cobbles were found, most of them weighing between 800 and 2000 g. Experimental research, along with 3D scanning and morphometric analysis (Ingram and Brandherm, 2023) sought to link these cobbles to prehistoric mining practices. The study argued that the crushing and pitting damage observed on the archaeological samples resulted from their use as tools.

Like the stone tools previously described in the region, these are unmodified cobbles; however, in this case, they are related with a Bronze Age context (fig. 6).

The investigation was complemented by elemental characterisation and LIA of copper ores from the mine, as well as archaeological objects from nearby Argaric sites of San Antón and Monteagudo. The LIA suggests that only one of the analysed objects (a bronze dagger blade without inventory number from the Orihuela Museum) could be related to the ores of the Segura Valley. Another bronze dagger, from grave 21 of Cerro de la Encina (Granada), could also match with this provenance (Brandherm et al., 2022).

Both the metabasite cobbles and the LIA results support the existence of small-scale mining activity in the Cerro de la Mina. This is an exceptional case due to the proximity between the mine and the Bronze Age settlement, similar to the Cerro de la Peluca in the Málaga province.

Survey in the eastern part of the Internal Zone of the Betic

This survey was aimed to improve the characterisation of trace element compositions and lead isotope analyses using MC-ICP-MS from the Cerro Minado, Pinar de Bédar, Sierra Cabrera and Sierra Almagrera/Herrerías (Murillo-Barroso et al., 2019; here, fig. 7). Although previous studies by I. Montero-Ruiz (1992) and N. Escanilla (2016) had already published composition analyses of these mines, neither trace element analyses nor LIA had been conducted.

The scarcity of archaeological evidence for prehistoric mining activities in the area, partly due to extensive modern landscape alteration, means that these works can only be confirmed through indirect evidence. In a subsequent publication, Murillo-Barroso et al. (2020) confirmed, through LIA of metallurgical remains and artefacts from Chalcolithic sites, the local exploitation of these mines. Specifically, evidence pointed to the

Fig. 6 – Cerro de la Mina (view from the south of Sierra de Orihuela), metabasite tool found in the site and view of the modern dumps at the base of the hill (after Brandherm et al., 2014).

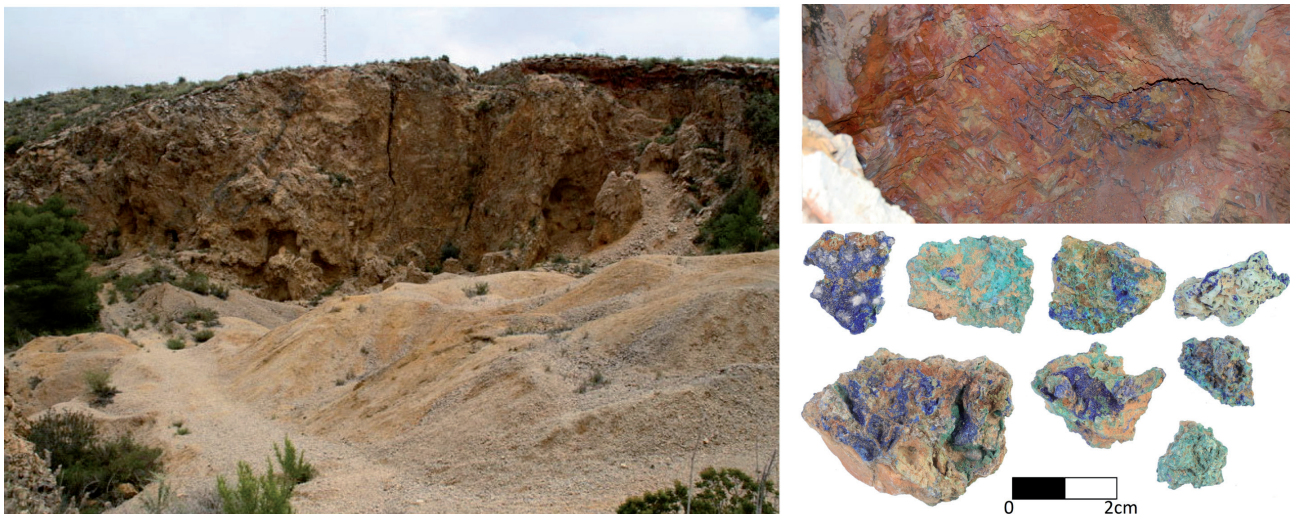

Fig. 7 – Left: Mina Aprovechado, Pinar de Bédar. Right: Detail of the mineralisation and some samples collected.

exploitation of Pinar de Bédar by the inhabitants of Las Pilas, while Cerro Minado was identified as the source for sites such as Santa Bárbara and Almizaraque. The possibility that Almizaraque and Las Pilas also exploited ore from Herrerías, albeit to a lesser extent, remains open.

This study reveals the possibility of the simultaneous use of different resources within a relatively small area, which reinforces the interpretation of metallurgy in the region as a small-scale activity. This directly reduces the archaeological visibility of mining activities, as the simultaneous exploitation of multiple ore sources results in lower extraction intensity at each individual site. Furthermore, the transport of copper ores to settlements for smelting significantly reduces the chances of preserving archaeological evidence within the mines themselves.

Argaric territory (provinces of Granada and Almería). The aim was to characterise them through lead isotope analysis (LIA) using MC-ICP-MS, and trace element analysis via Q-ICP-MS (Murillo-Barroso et al., 2025a). This study examined copper mines situated along the northern fringes of the Sierra Nevada, Sierra Arana, Sierra de Baza, Sierra de los Filabres and Sierra de las Estancias, all part of the Betic Cordillera and distributed in the three superposed tectonic complexes. From bottom to top: the Nevado-Filábride, Alpujárride and Maláguide complexes.

The main copper deposits at the Nevado-Filábride Complex are those located at the northern edge of the Sierra Nevada. Among the six mines visited, only one - Santa Constanza – yielded archaeological evidence of

Fig. 8 – Left: Zurgena Mine. Right: Some copper ore samples and a prehistoric sherd recovered from Zurgena mine.

In 2023, another survey was conducted in an inner area of this region covering the mines of Zurgena (fig. 8), Huércal Overa and Pulpí. Eight copper deposits were documented, but archaeological evidence of possible prehistoric works (limited to a few pottery sherds) was only recovered in two of them. Trace element and LI characterisation of these outcrops is still ongoing, although pXRF screening of ore samples revealed that these are polymetallic deposits containing arsenic (up to 6 %), antimony, lead and zinc (table 1).

Survey in the inner parts of the Betic Cordillera

A survey carried out between 2015 and 2018 focused on sampling copper mines located in the inland areas of the

prehistoric exploitation, in the form of stone hammers and pottery (fig. 9).

In the Alpujárride Complex, copper ores were sampled from Filón Violeta, De La Cruz, San José, Don Jacobo and José Miguel-1 and -2 mines. No direct evidence of prehistoric exploitation was found at these mines, although prehistoric occupation dating back to the Neolithic has been documented in the surrounding areas.

Copper minerals in the Maláguide Complex were sampled at Venta del Molinillo, Peñón Colorado and Cerro de la Mina mines, the latter being just a few hundreds of meters from the Neolithic settlement of Cerro de Los López (Martínez García et al., 1988). Both Peñón Colorado and Cerro de la Mina yielded prehistoric pottery and stone hammers, suggesting a probable prehistoric exploitation.

Nº	Mine	PROV.	As	Sb	Pb	Zn	Ni	Ag	Co	Stone Tools	LIA
1	Las Escaurias	MA	×	×	×			×			
2	Montecortillo	MA	×		×						
3	Horadada	MA					×		×		
4	San Pedro	MA	×			×	×		×		3
5	Cardenillo	MA	×						×		3
6	Lagar de los Huescas	MA									
7	Lagar de las Animas	MA									2
8	Cerro Coronado	MA				×					
9	Los Bravos	MA									
10	El Ángel	MA	×								
11	Santopitar	MA				×			×		
12	Casacara	MA	×		×	×			×	×	1
13	La Peluca	MA								×	
14	Caserón de las Palomeras	MA				×					
15	Venta del Molinillo	GR	×	×	×	×		×			5
16	La Estrella	GR									
17	Probadora	GR	×	(×)							1
18	Santa Constanza	GR								×	3
19	Filón Violeta	GR	×	×	×						1
20	De La Cruz	GR	×	×	×	×		×			3
21	San José	GR	×		×	×					
22	Hernán Cortés	GR	(×)								1
23	Previsión	GR	×								3
24	Peñoncillo	GR	(×)								2
25	José Miguel 1	AL									
26	José Miguel 2	AL	×				×				1
27	Don Jacobo	AL	×	(×)	×			(×)			4
28	Peñón Colorado	AL								×	2
29	Cerro de la Mina	AL	×		×					×	3
30	Zurgena	AL									
31	Cerro Minado	AL	×			×	×	(×)	×	×	20
32	Pinar de Bédar	AL	×			×					13
33	Cortijo Grande	AL									1
34	Mojacar	AL	(×)	(×)							
35	Herrerías	AL	×	(×)	×			×		×	6
36	La Estrella	AL			×						2
37	Cala de Oro	AL	×		×						
38	Pulpí	AL	×								
39	Alcolea	AL	×	×	×	×	(×)	(×)			4
40	Filón Consuelo	MU	×	×		×				×	
41	Balsicas	MU		×						×	
42	La Diosa S. de Enmedio	MU	×	×	×	×					
43	Santa Isabel S. de Enmedio	MU		(×)	×						
44	Castillarejos (S. Tercia)	MU	×								
45	Zarzicos	MU	×								

Table 1 – General composition patterns of copper ores from the Southeast. PROV = Province. MA = Málaga, GR = Granada, AL = Almería, MU = Murcia.

46	Minas de Merzu (S. de Torrecilla)	MU									
47	Rambla Roja	MU			(×)						
48	Cortijo de Los Tostones	MU		×	×		×				
49	Mina Adela	MU									
50	Santomera C. de la Mina	MU	×							×	10
51	La Francesa-Zurgena	AL				×					
52	Las Minas-Zurgena	AL			×	×					
53	Fuente del Pino-Zurgena	AL				×					
54	Castillo de Santa Bárbara	AL									
55	Molino del Judío	AL	×		×	×					
56	Rambla del Saltador	AL									
57	Diputación Fuente	AL	×								
58	El Zurdo	AL	×	×	×	×					

Table 1 (continued) – General composition patterns of copper ores from the Southeast. PROV = Province. MA = Málaga, GR = Granada, AL = Almería, MU = Murcia.

Fig. 9 – Left: Mina Previsión (Sierra de Baza, Granada). Right: copper ore fragments and a stone hammer from Mina de Santa Constanza (Sierra Nevada, Granada).

At the same time, the study publishes new trace element and LIA results from the argaric settlements of Cuesta del Negro and Terrera del Reloj, located in Granada province, just 10 to 50 km from the sampled mines. The comparative LIA study including previous data from two other Bronze Age sites in the area, Cerro de la Encina and Cerro de San Cristóbal (Murillo-Barroso et al., 2015) suggests that copper from mines across all three tectonic complexes may have been used in Bronze Age metallurgy. The study also confirms the presence of metal originating from Cerro Minado, further supporting its exploitation during the Bronze Age.

A GENERAL PERSPECTIVE

In recent years, some field surveys in several parts of the internal Betic ranges have significantly increased our knowledge of the copper resources available in this extensive area.

Most of the recent researchers visited the mines, looked for evidence of prehistoric works, and sampled ores to be characterised by trace elements and LIA. Table 1 compiles data on the elemental composition of copper ores, the identification of stone tools and the number of LIA results obtained from each mine.

Copper ores are widely distributed throughout the Betic Ranges, but in general they consist of small mines or outcrops. Surface copper ores are oxides and carbonates, with iron and arsenic as the main impurities. However, diverse polymetallic combinations with elements such as Sb, Ag, Ni, Co, Zn or Pb have also been identified.

Elemental data is now available for ores from 58 mines, but stone tools have only been found at 10 of these sites. Most of these tools are unmodified cobbles made of metabasites or other hard rocks. The absence of clearly grooved stone hammers, which are common in other Iberian mines, along with the limited number of lithic tools found in each mine, contrasts with the more abundant and clearer prehistoric mining evidence from areas such as the Sierra Morena (north of the Guadalquivir Valley: Domergue, 1987, Hunt Ortiz, 2003). For example, L. Arboledas Martínez et al. (2023) compiled data on 116 copper mines in the provinces of Badajoz, Jaén, Sevilla, Huelva and Córdoba, most of which presented grooved stone hammers as the main archaeological indicator. Recent surveys in Badajoz (Hunt-Ortiz et al., 2025) and Córdoba have documented hundreds of these tools.

In our own surveys in the Alto Guadiato valley and the southern part of Los Pedroches (Córdoba), an area where over 40 copper deposits had been listed in geological documentation; we were only able to relocate 26, probably due to modern landscape alteration (Pérez-L'Huillier et al. 2022). This clearly suggests that copper resources accessible to prehistoric communities were far more abundant than what is visible today. Evidence of prehistoric mining (stone hammers and pottery sherds) was documented in five of these deposits—previously unknown as prehistoric sites. At the intensively surveyed Los Perules mine (Hinojosa del Duque), 174 stone hammers and 52 fragments of prehistoric pottery were recovered. Characterization of the tools is still ongoing, but most are grooved boulders, while 79 % of the pottery can be attributed to the Copper Age. Trace element compositions and LIA are still ongoing, but preliminary pXRF analyses revealed a high-purity copper ore with only minor impurities.

A similar situation was documented at Las Minillas mine (Granja de Torrehermosa, Badajoz), where prehistoric mining and on-site smelting evidence have been documented (Hunt Ortiz et al., 2017; Hunt Ortiz and Ling, 2023). Although with a later chronology (Late Bronze Age), more than 900 stone hammers have been documented up to now in that single mine (Hunt Ortiz et al., 2025).

This clearly contrasts with the ten mines in the Betic ranges where only fragments of possible tools have been identified, with the exception of Cerro de la Mina de Santomera, which provides more substantial archaeological evidence.

Copper mines in the Betic Cordillera were clearly exploited during the Chalcolithic period, as confirmed by M. Murillo-Barroso et al. (2020). The case of Pinar de Bédar is particularly relevant: although no lithic tools have been recovered from the mine, LIA and trace elements composition conclusively shows that these ores were used at the Chalcolithic settlement of Las Pilas.

Cerro Minado remains the only mine dated to the second half of the 3rd millennium BC based on radiocarbon dating. However, its exploitation seems to have continued into the El Argar Bronze Age, as indicated by LIA matches with Argaric artefacts. Nevertheless, the scale of mining activity appears to have been relatively limited, suggesting a small-scale production.

Most copper mines in the region are located within 10 km of Chalcolithic or Bronze Age settlements. Ore processing, however, typically occurred within the settlements rather than directly at the mines.

Sites such as Cerro de la Mina de Santomera (Murcia) and Cerro de la Peluca (Málaga) are particularly noteworthy, as both settlements are located on the same hill as the copper mines. This spatial proximity complicates the task of demonstrating the simultaneity of mining and habitation without more detailed archaeological investigation (Ingram and Brandherm, 2023).

Copper resource exploitation in the Betic region has a long and significant history, though the Late Bronze Age remains less well defined. During the first millennium BC, Phoenician, Iberian, and Roman interests predominantly focused on lead/silver and iron resources. Cl. Domergue (1987) and L. Arboledas Martínez (2010) mentioned only a single copper mine, La Paloma (Bayarque, Almería), which provides definitive evidence of Roman exploitation. The main phase of Roman mining activity in this region occurred during the Late Republic and the 1st century AD.

Overall, the research conducted, highlights the complexity and variability of copper mining practices in the Betic region. It also underscores the importance of continued archaeological investigation to better understand the scale, chronology, and organisation of mining activities across different historical periods.

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