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Copper Supply Networks in the Early Bronze Age of South-east Spain: New Evidence from the Lower Segura Valley

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ABSTRACT

The range of copper sources and the nature of metal supply networks used by the El Argar culture of south-east Spain have been the subject of a long-running debate. On one side of this debate we have a model that envisages supply for much of the El Argar culture coming from a closely circumscribed region and controlled centrally by a political élite, while on the other side we have a model of a more decentralised supply network drawing on a wider, geographically more dispersed range of ore sources that is lacking the same level of political control. The available archaeometallurgical data are not entirely conclusive in this respect. While results from the existing, comparatively small body of lead isotope analyses have been taken to support, at least to some extent, the idea of a single main source region supplying most if not all of the El Argar culture area with copper, results from the much larger but not easily interpreted body of minor-element analyses would appear to lend support to the notion of a more decentralised supply. In this contribution we present new analytical data from the Lower Segura Valley, both from local copper ores and from local El Argar artefacts, which provide new insights relevant to this debate.

1. Introduction

This paper presents results from a programme of analyses undertaken on copper ores from the Lower Segura Valley, straddling the provinces of Alicante and Murcia in south-east Spain, and on metal objects from sites of the El Argar culture in that same study area (Figure 1). Our programme of analyses was conducted following a field survey project that aimed at identifying evidence for pre-modern mining activities in the Lower Segura Valley (Brandherm and Maass, 2010; Brandherm *et al.*, 2013; 2014). Both in terms of the archaeology of its pre-modern mining remains and of the characterisation of relevant ore bodies, the study area has received relatively little attention in comparison to the much larger nearby mining district of Cartagena and Mazarrón, as well as other mining areas further afield in southern Iberia.

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The principal aim of our project was to remedy that situation and enable a full assessment of the significance of extractive industries and their contribution to past metal supply networks in the region.

One of the main points of interest in this regard was to determine to what extent the exploitation of local copper ores might have contributed to the metal supply of Early Bronze Age (EBA) settlements in the region. During the EBA the Lower Segura Valley constituted the northernmost expanse of the El Argar culture area (Brandherm, 1996; Martínez Monleón, 2014), and the extent to which copper supply within the El Argar culture may have been centrally controlled by a political élite continues to be a matter of considerable debate (Lull Santiago *et al.*, 2010a; 2010b; Montero Ruiz and Murillo Barroso, 2010).

On one side of that debate we have a model according to which the bulk of El Argar copper would have originated from the Linares mining district in the eastern Sierra Morena,

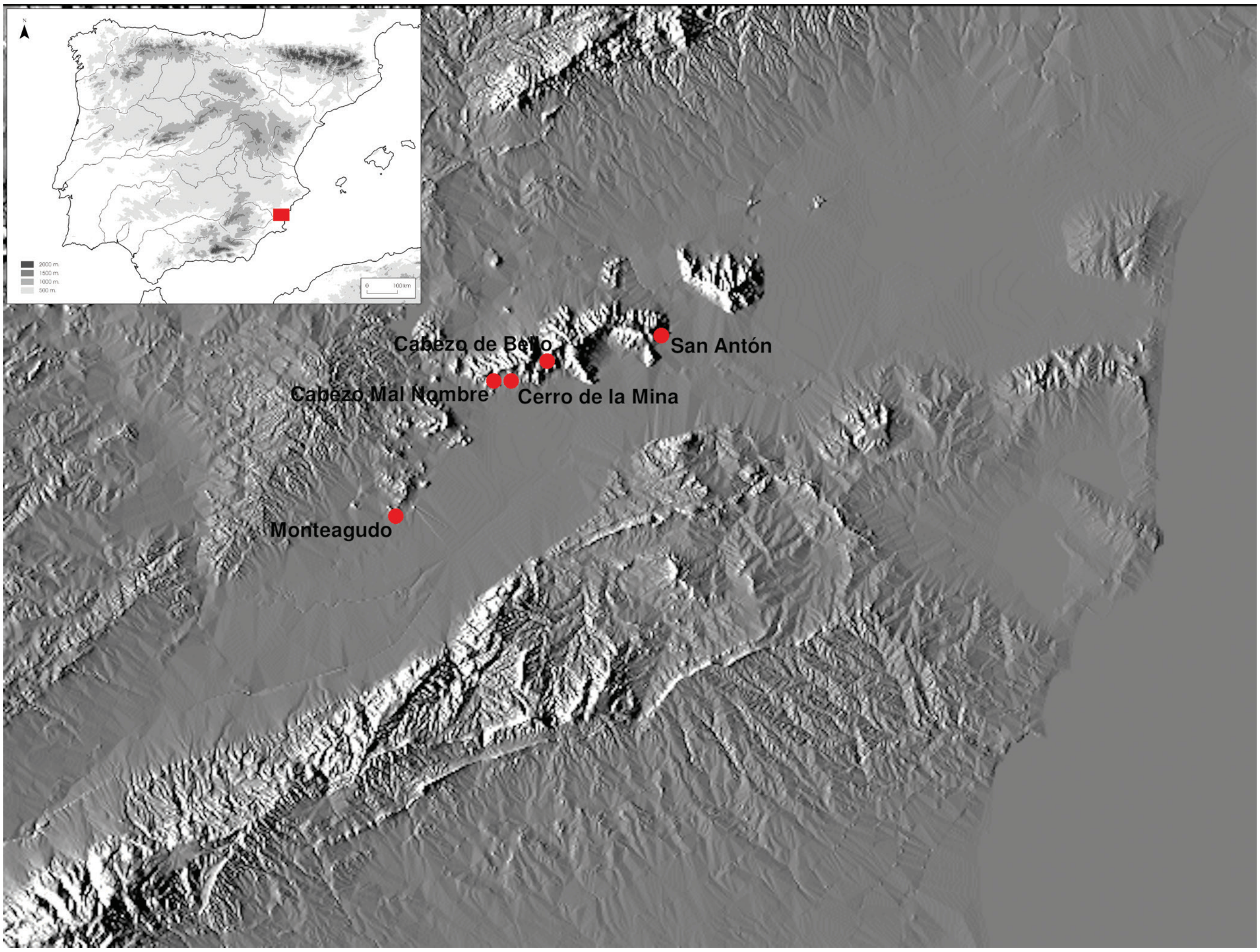

Figure 1. Map of the study area with site names mentioned in the text.

with the distribution of the metal tightly controlled by the ruling class of an emerging El Argar state. This model was originally based on a limited set of lead isotope data obtained as part of the Gatas project through a programme of analyses undertaken at the Oxford Isotrace Laboratory (Stos-Gale *et al.*, 1999). Subsequently it also came to draw on the lack of direct evidence for extractive metallurgy from El Argar contexts other than those of the Linares mining district (Escanilla, 2016, pp.430–432).

On the other side of the debate we have a model of multiple, geographically dispersed ore sources providing El Argar society with copper through a non-centralised supply system. This model was originally informed by statistically significant variation in the trace-element contents of copper-base metal objects from a range of different El Argar settlements, which seems to suggest that not all of the relevant sites were supplied from the same ore body and clearly contradicts the notion of a single supply source for El Argar copper (Montero Ruiz, 1999, p.350). Subsequent additions to the body of relevant lead isotope data also appear to indicate that different sources contributed to the copper supply of El Argar society (Stos-Gale, 2001, p.454; Müller-Kissing, 2014, p.56; Murillo-Barroso *et al.*, 2015, pp.152–154), but the number of available analyses still only provides limited coverage of the very diverse range of relevant ore bodies in southern Spain, and the respective body of data continues to present some difficulties of interpretation which only an approach combining lead isotope and trace-element data can potentially overcome (Montero Ruiz, 2018, pp.322–324; Murillo-Barroso *et al.*, 2019, pp.606–607).

The isotopic and trace-element characterisation of ore bodies and El Argar copper-base metal objects from the Lower Segura Valley presented here constitutes an important step in filling the remaining gaps in this jigsaw.

2. Methodology

As part of our field survey project, copper ore samples were collected at different locations in the Sierra de Orihuela and Sierra de Santomera, either directly from surface outcrops of ore bodies or from spoil tips left by modern exploration or mining activities. None of the analysed ore samples was retrieved from an EBA context, although several of the respective sampling locations are situated in the immediate vicinity of prehistoric settlement sites (Cabezo Mal Nombre, Cerro de la Mina).

The analyses of ore samples from our survey were carried out in the German Mining Museum at Bochum (Deutsches Bergbau-Museum Bochum), employing X-ray diffraction (XRD) to establish the types of minerals present, and inductively coupled plasma mass spectrometry (ICP-MS) to determine their chemical composition. Samples with a copper content of less than 5 % were excluded from the subsequent lead isotope analysis. Likewise, sample preparation for the latter was undertaken at the German Mining Museum, with subsequent analysis through multicollector-inductively coupled plasma mass spectrometry (MC-ICP-MS) conducted at the University of Frankfurt (for the relevant method statement, including measurement conditions, see Klein *et al.*, 2009, p.64).

Further ore samples from the Lower Segura Valley referenced in this study and collected prior to the aforementioned survey project were analysed by X-ray fluorescence (XRF) for their elemental composition, as part of the project "Archaeometallurgy of the Iberian Peninsula" at the National Museum of Archaeology (Museo Arqueológico Nacional) in Madrid (Rovira Llorens and Montero Ruiz, 2018). As part of that same project, one sample (PA13535B) was also analysed for its lead isotope ratios through thermal ionisation mass spectrometry (TIMS) at the Geochronology and Isotope Geochemistry Research Laboratory of the University of the Basque Country (SGIker).

The elemental and lead isotope analysis of copper-base archaeological objects for the present study was also carried out by SGIker, on bulk samples drilled close to the centre of the relevant artefacts, using quadrupole inductively coupled plasma mass spectrometry (Q-ICP-MS) for elemental analysis and MC-ICP-MS for lead isotope analysis (for the relevant method statement, including measurement conditions, see Rodríguez *et al.*, 2020, pp.875–876).

Previously published analyses of copper-base metal artefacts from the Oxford Archaeological Lead Isotope Database (OXALID) referenced in this study had been analysed via XRF for their elemental composition and through TIMS for their lead isotope ratios at the Oxford Isotrace Laboratory (Stos-Gale, 2001, p.445). The results of the TIMS method used by SGIker and the Oxford Isotrace Laboratory have been shown to be directly comparable to those from MC-ICP-MS analyses such as those presented in the present study (Stos-Gale and Gale, 2009, pp.196–198).

3. Copper resources in the Lower Segura Valley

According to the ICP-MS analyses carried out at the German Mining Museum (Table 1), the copper ore from the study area is quite pure, with a low to moderate presence of arsenic, depending on the mines sampled. The As / Cu ratio ranges from 0.02 % to 5.24 %, with an average of 1.78 %. Arsenic content is highest in the sample from Cabezo Mal Nombre in the Sierra de Santomera and is lowest in the samples from Cabezo de Bello in the Sierra de Orihuela, with the samples from Cerro de la Mina falling in between. Processing of ore with these characteristics will produce copper with variable arsenic content, but it is unlikely that high-arsenic pieces (>3% As) are produced from such ore, as the relative volatility of arsenic will generally produce metal with a lower average arsenic content than is found in the ore from which that metal has been smelted, and this effect will be further enhanced if that same metal is then subjected to subsequent pyrotechnical processes (Craddock, 1995, pp.285–290). Other elements do not have a significant presence, except for iron (Fe) in samples where this element is in the majority and which we can therefore classify as Cu-Fe ore. The amounts of sulphur detected are extremely low, which means that we are dealing with oxide, hydroxide or carbonate minerals rather than chalcopyrite or other primary sulphides. X-ray diffraction (XRD) confirms that samples are mainly malachite, with paratacamite also present, and iron appearing as goethite or hematite. The gangue is mainly composed of quartz, albite, muscovite and paragonite, with calcite present in only one instance (sample SAN 24-2-1).

These features allow the ores to be attributed to Escanilla's (2016, pp.328–330) Class 3, with the samples falling into his Groups B or C, based on their greater or lesser proportion of copper. These data coincide with the ores studied by Escanilla (5 samples) from Cerro de la Mina, labelled as Cerro de las Fuentes in his study (Escanilla, 2016, pp.75–85 and Annex I, ID 89; pp.521–525). Ores of Group 3B in particular would have been easily processed with the technology available to EBA communities in the study area (Escanilla, 2016, p.329). Ore samples from Cerro de la Mina were also analysed by XRF as part of the "Archaeometallurgy of the Iberian Peninsula" project (Table 1). Although poorer in arsenic than the newly analysed samples presented here, these show the same trend and identify a sporadic presence of cobalt (Co) and bismuth (Bi), as do the analyses conducted as part of Escanilla's study. It is also interesting to note that in all analyses undertaken the lead content is low, below the detection limit for some of the analytical techniques involved. In the new analyses presented here, the Pb / Cu ratios do not usually exceed 0.01 % or 100 ppm, with a maximum value of 0.03 % Pb / Cu.

The absence of relevant proportions of antimony, silver and nickel means that the metal obtained from these ores would fall into Group 2 (Cu + As) according to the classification established by Pollard *et al.* (2018). Articulating a more specific relationship between the different categories of ores according to Escanilla (2016) and that of finished objects according to Pollard *et al.* (2018) is rendered difficult by the coarse-grained nature of the latter classification scheme and by the complex nature of the chemical processes involved in smelting operations.

4. Metal objects from San Antón and Monteagudo

A set of 12 objects, mainly dagger blades, have been analysed to determine their composition, using ICP-MS in the Geochronology and Isotope Geochemistry Research

Table 1. Chemical composition of copper ores from the Lower Segura Valley (1–13: ICP-MS analyses carried out at the German Mining Museum [Element XR, Thermo Fisher Scientific]); 14–22: XRF analyses carried out at the National Museum of Archaeology [X-MET 920MP, Metorex]; mdl = method detection limit).

No.	Lab Code	Field Sample ID	Provenance	Sr	Ag	Sn	Sb	Te	Bi	Pb	U	Co	Cu	Ni	Se	As	Zn	Fe	FeO
				ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	%	ppm	ppm	%	%	%	%
1	4002/13	ORI-28-2-1	Cabezo de Bello	28	20	47	5	3	120	4	5	22	6.37	34	<4	0.003			3.26
2	4003/13	ORI-30-1-1	Cabezo de Bello	28	1	61	2	1	1	2	5	9	6.56	19	4	0.001			0.92
3	4004/13	ORI-31-2-1	Cabezo de Bello	23	1	59	2	<1	4	2	7	14	1.90	26	<4	0.001			1.62
4	4005/13	SAN-2-0-7	Cabezo Mal Nombre	110	6	36	7	1	175	39	34	9	20.3	40	5	1.06			1.01
5	4006/13	SAN-64-5-3	Cerro de la Mina	56	4	49	23	<1	225	38	26	17	22.3	53	5	0.75			3.11
6	4007/13	SAN-11-0-3	Cerro de la Mina	42	4	32	3	<1	38	14	8	2	4.71	11	<4	0.06			0.39
7	4008/13	SAN-16-0-4	Cerro de la Mina	79	115	57	8	<1	105	23	22	2	13.9	9	4	0.73			1.69
8	4009/13	SAN-33-6-1	Cerro de la Mina	135	14	85	7	<1	81	13	18	485	7.60	200	<4	0.03			5.16
9	4010/13	SAN-27-5-1	Cerro de la Mina	44	13	48	30	2	61	10	32	56	13.8	96	15	0.15			21.3
10	4011/13	SAN-14-0-2	Cerro de la Mina	50	25	46	12	<1	50	9	21	10	25.9	17	4	0.19			2.28
11	4012/13	SAN-33-7-2	Cerro de la Mina	34	1	14	10	<1	22	4	2	71	6.55	65	<4	0.03			1.02
12	4013/13	SAN-24-2-1	Cerro de la Mina	105	1	49	120	<1	12	9	30	46	11.1	81	7	0.18			24.2
13	4014/13	SAN-44-2-1	Cerro de la Mina	38	4	36	24	<1	31	3	12	110	3.22	69	<4	0.12			3.71
14	PA13535A	—	Cerro de la Mina		10	<mdl	<mdl		<mdl	1800			13.2	<mdl		<mdl	<mdl	1.43	
15	PA13535B	—	Cerro de la Mina		520	<mdl	100		<mdl	2000			25.8	<mdl		1.10	<mdl	8.76	
16	PA13535C	—	Cerro de la Mina		170	<mdl	<mdl		<mdl	100			53.5	<mdl		<mdl	<mdl	2.01	
17	PA13535D	—	Cerro de la Mina		270	<mdl	<mdl		<mdl	<mdl			7.28	<mdl		<mdl	<mdl	4.44	
19	PA13535E	—	Cerro de la Mina		200	<mdl	<mdl		<mdl	1400			46.2	<mdl		<mdl	<mdl	0.74	
20	PA13535F	—	Cerro de la Mina		260	<mdl	<mdl		<mdl	1800			18.9	<mdl		<mdl	<mdl	2.07	
21	PA13536A	—	Cerro de la Mina		190	<mdl	<mdl		<mdl	2200			35.0	<mdl		<mdl	<mdl	1.31	
22	PA13793	—	Cerro de la Mina		160	<mdl	<mdl		<mdl	6700			29.7	<mdl		<mdl	1.58	1.91	

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No.	Lab Code	Field Sample ID	Provenance	Na2O	BaO	MgO	Al2O3	SiO2	P2O5	S	CaO	TiO2	MnO	ZnO	K2O
				%	%	%	%	%	%	%	%	%	%	%	%
1	4002/13	ORI-28-2-1	Cabezo de Bello	0.71	0.02	0.45	3.65	74.7	0.17	0.03	0.32	0.54	0.03	0.01	1.41
2	4003/13	ORI-30-1-1	Cabezo de Bello	0.77	0.01	0.14	5.21	79.6	0.09	0.01	0.20	0.33	0.02	0.01	1.36
3	4004/13	ORI-31-2-1	Cabezo de Bello	0.49	0.03	0.17	6.27	78.2	0.11	0.00	0.19	0.32	0.04	0.01	2.70
4	4005/13	SAN-2-0-7	Cabezo Mal Nombre	0.43	0.01	0.39	4.52	60.1	0.13	0.06	0.90	1.51	0.01	0.02	0.38
5	4006/13	SAN-64-5-3	Cerro de la Mina	1.20	0.01	0.09	11.7	50.0	0.07	0.03	0.26	0.44	0.03	0.02	0.89
6	4007/13	SAN-11-0-3	Cerro de la Mina	0.64	0.003	0.09	7.46	80.3	0.15	0.01	0.30	0.50	0.002	0.01	0.66
7	4008/13	SAN-16-0-4	Cerro de la Mina	1.30	0.01	0.06	12.7	56.5	0.07	0.06	0.15	0.24	0.002	0.01	1.25
8	4009/13	SAN-33-6-1	Cerro de la Mina	2.91	0.01	0.04	7.64	58.9	0.08	0.07	1.80	3.00	0.01	0.01	1.44
9	4010/13	SAN-27-5-1	Cerro de la Mina	0.63	0.01	0.23	5.22	46.6	0.30	0.11	0.66	1.10	0.03	0.01	0.39
10	4011/13	SAN-14-0-2	Cerro de la Mina	0.51	0.004	0.06	8.05	52.1	0.16	0.03	0.67	1.12	0.005	0.01	0.40
11	4012/13	SAN-33-7-2	Cerro de la Mina	0.09	<0.003	0.31	0.09	85.5	0.01	0.03	0.47	0.79	0.03	0.01	0.11
12	4013/13	SAN-24-2-1	Cerro de la Mina	0.43	0.01	0.22	3.65	45.2	0.46	0.02	1.73	2.88	0.08	0.04	1.18
13	4014/13	SAN-44-2-1	Cerro de la Mina	0.82	0.002	0.09	8.24	79.5	0.06	0.01	0.11	0.19	0.001	0.01	0.58
14	PA13535A	—	Cerro de la Mina												
15	PA13535B	—	Cerro de la Mina												
16	PA13535C	—	Cerro de la Mina												
17	PA13535D	—	Cerro de la Mina												
19	PA13535E	—	Cerro de la Mina												
20	PA13535F	—	Cerro de la Mina												
21	PA13536A	—	Cerro de la Mina												
22	PA13793	—	Cerro de la Mina												

Table 2. Chemical composition of El Argar copper-base metal objects from the Lower Segura Valley (Q-ICP-MS analyses carried out at the Geochronology and Isotope Geochemistry Research Laboratory of the University of the Basque Country [XSeries 2, Thermo Scientific]; mdl = method detection limit).

Lab Code	Object Category	Museum	Inventory Number	Provenance	Bibliography
D13/1	halberd	Museo Arqueológico Provincial de Alicante	CS8957	San Antón (?)	Brandherm, 2003, no. 1457A
D13/2	knife-dagger	Museo Arqueológico Provincial de Alicante	CS8965	San Antón	Brandherm, 2003, no. 1257
D13/3	dagger	Museo Arqueológico Provincial de Alicante	CS8967	San Antón (?)	Brandherm, 2003, no. 1502
D13/4	dagger	Museo Arqueológico Provincial de Alicante	CS8970	San Antón	Brandherm, 2003, no. 1501
D13/5	dagger	Museo Arqueológico Provincial de Alicante	CS8973	San Antón	Brandherm 2003, no. 1232
D13/6	dagger	Museo Arqueológico Provincial de Alicante	CS8978	San Antón	Brandherm, 2003, no. 743
D13/7	dagger	Museo Arqueológico Provincial de Alicante	CS8979	San Antón (?)	Brandherm, 2003, no. 744
D13/8	dagger	Museo Arqueológico Provincial de Alicante	CS8980	Monteagudo	Brandherm, 2003, no. 481
D13/9	axe	Museo Arqueológico Comarcal de Orihuela	B 383	San Antón	Simón García, 1998, fig. 5,1
D13/10	dagger	Museo Arqueológico Comarcal de Orihuela	B 385	San Antón	Brandherm, 2003, no. 585
D13/11	dagger	Museo Arqueológico Comarcal de Orihuela	SA (CB) 3	San Antón	Brandherm, 2003, no. 632
D13/12	dagger	Museo Arqueológico Comarcal de Orihuela	–	San Antón	Brandherm, 2003, no. 699

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Lab Code	Sb	Ba	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm
	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
D13/1	69.50	1.45	0.051	0.077	<mdl	<mdl	0.006	0.002	0.007	0.001	<mdl	0.001	0.003	<mdl
D13/2	166.20	1.07	<mdl	<mdl	<mdl	<mdl	0.002	<mdl	0.002	<mdl	<mdl	<mdl	0.001	<mdl
D13/3	56.22	3.18	0.057	0.096	0.011	<mdl	0.008	0.002	0.009	0.001	<mdl	0.001	0.003	<mdl
D13/4	7.50	1.83	0.084	0.169	0.017	<mdl	0.014	0.003	0.012	0.002	<mdl	0.002	0.005	<mdl
D13/5	50.47	2.91	0.035	0.067	<mdl	<mdl	0.005	0.001	0.005	0.001	<mdl	0.001	0.002	<mdl
D13/6	15.20	2.40	<mdl	<mdl	<mdl	<mdl	0.002	0.000	0.002	0.000	<mdl	0.000	0.001	<mdl
D13/7	6.39	3.46	0.059	0.112	0.012	<mdl	0.010	0.001	0.010	0.001	<mdl	0.001	0.004	<mdl
D13/8	176.56	0.48	0.033	0.035	0.016	<mdl	0.002	0.000	0.002	<mdl	<mdl	<mdl	0.001	<mdl
D13/9	38.49	0.91	0.049	0.131	0.011	<mdl	0.009	0.002	0.008	0.001	<mdl	0.001	0.003	<mdl
D13/10	188.00	3.86	0.050	0.093	0.010	<mdl	0.009	0.002	0.008	0.001	<mdl	0.001	0.003	<mdl
D13/11	42.39	16.82	0.327	0.712	0.087	0.297	0.059	0.012	0.061	0.007	0.042	0.007	0.020	<mdl
D13/12	375.60	4.74	0.404	0.783	0.116	0.290	0.063	0.016	0.066	0.010	0.045	0.009	0.024	<mdl
MDL (ppm)	1.12	0.53	0.028	0.043	0.011	0.228	0.0001	0.0001	0.0001	0.0001	0.013	0.0001	0.0001	17.271

Table 2. Chemical composition of El Argar copper-base metal objects from the Lower Segura Valley (Q-ICP-MS analyses carried out at the Geochronology and Isotope Geochemistry Research Laboratory of the University of the Basque Country [XSeries 2, Thermo Scientific]; mdl = method detection limit). (Continuation)

Lab Code	Yb	Lu	Pb	Bi	Th	U	Na	Mg	Al	K	Ca	V	Cr	Fe
	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
D13/1	0.003	0.000	34.54	268.80	0.02	0.19	239.00	141.30	145.40	311.30	405.70	11.24	<mdl	111.00
D13/2	<mdl	<mdl	708.40	318.70	0.28	<mdl	74.40	25.86	21.97	<mdl	<mdl	0.37	<mdl	<mdl
D13/3	0.002	0.000	41.11	159.92	0.03	0.05	295.92	122.16	165.36	456.00	321.44	5.60	<mdl	88.56
D13/4	0.003	0.000	<mdl	554.30	0.04	0.03	591.60	152.00	160.60	577.00	487.50	6.53	7.92	128.80
D13/5	0.002	0.000	79.18	99.40	0.03	<mdl	770.40	954.00	97.01	604.30	1405.00	5.62	9.69	164.90
D13/6	0.001	<mdl	<mdl	92.34	0.04	<mdl	858.69	70.43	20.41	494.55	271.17	2.12	<mdl	<mdl
D13/7	0.003	<mdl	50.52	82.64	0.08	0.31	<mdl	109.04	5866.40	<mdl	<mdl	4.75	14.91	166.64
D13/8	0.001	<mdl	50.98	62.52	0.07	<mdl	212.72	109.20	<mdl	312.72	<mdl	0.46	<mdl	<mdl
D13/9	0.003	0.001	44.68	547.28	0.07	0.04	<mdl	139.76	79.89	80.48	231.04	1.73	<mdl	160.40
D13/10	0.003	0.000	67.03	51.18	0.03	0.10	98.80	78.59	99.12	105.84	<mdl	4.99	10.35	118.48
D13/11	0.016	0.003	16.23	118.70	0.15	0.14	2293.00	374.80	594.50	2021.00	1664.00	13.51	9.38	383.50
D13/12	0.018	0.004	38.79	298.64	0.14	0.47	117.52	231.92	509.20	220.88	166.72	23.52	<mdl	269.04
MDL (ppm)	0.0001	0.0001	14.18	2.35	0.02	0.02	68.50	16.17	19.39	72.17	86.94	0.15	4.85	37.16

Table 2. Chemical composition of El Argar copper-base metal objects from the Lower Segura Valley (Q-ICP-MS analyses carried out at the Geochronology and Isotope Geochemistry Research Laboratory of the University of the Basque Country [XSeries 2, Thermo Scientific]; mdl = method detection limit). (Continuation)

Lab Code	Mn	Co	Ni	Cu	Zn	Ga	As	Se	Sr	Y	Ag	Cd	Sn
	ppm	ppm	ppm	%	ppm	ppm	%	ppm	ppm	ppm	ppm	ppm	ppm
D13/1	2.55	2.13	63.83	78.35	230.80	0.06	5.20	10.35	27.65	0.06	373.60	<mdl	<mdl
D13/2	2.17	0.29	213.10	93.97	234.20	<mdl	4.49	10.47	10.51	<mdl	20.77	<mdl	<mdl
D13/3	2.78	1.53	7.83	84.56	221.28	0.05	2.58	10.25	32.90	0.05	63.06	<mdl	<mdl
D13/4	4.66	2.30	2.42	87.55	226.20	0.05	4.88	18.53	89.11	0.06	72.59	<mdl	<mdl
D13/5	2.88	9.41	44.25	88.34	228.30	0.26	2.28	4.72	183.50	0.03	108.60	0.06	<mdl
D13/6	1.25	1.26	1.76	89.24	227.07	<mdl	5.95	5.75	43.25	<mdl	51.27	0.07	<mdl
D13/7	18.68	1.60	7.35	92.40	284.48	0.86	3.25	4.88	<mdl	0.05	24.88	0.06	<mdl
D13/8	1.48	3.00	132.64	80.88	195.44	<mdl	0.79	8.90	10.58	<mdl	43.97	<mdl	25192.00
D13/9	1.84	0.43	1.80	93.36	220.08	0.07	4.55	15.87	17.51	0.03	52.06	0.07	<mdl
D13/10	1.85	6.31	52.94	88.56	223.52	<mdl	0.97	7.18	14.36	0.03	137.28	0.02	546.56
D13/11	4.47	7.10	120.40	87.56	212.90	0.19	5.29	12.95	209.60	0.21	28.76	0.06	<mdl
D13/12	11.54	5.48	30.21	91.68	233.84	0.23	0.82	34.07	7.80	0.23	13.04	0.12	56128.00
MDL (ppm)	0.30	0.06	1.54	2614.01	9.39	0.04	29.12	1.01	6.63	0.02	9.82	0.02	104.37

Laboratory of the University of the Basque Country (Table 2). The analysed objects are from the two regional El Argar centres of Monteagudo and San Antón, situated in strategic positions along the Lower Segura Valley (*cf.* Brandherm, 1996). A smaller El Argar settlement exists at Cerro de la Mina, from whose immediate vicinity most of the analysed ore samples were obtained, but the site remains unexcavated and so far has not yielded any documented finds of copper-base metal objects of EBA date. The same holds true for the less securely dated prehistoric settlement at Cabezo Mal Nombre.

Most analysed objects (9) are from arsenical copper with high proportions of arsenic (> 2% As), reaching a maximum value of 5.3 % As in the two-rivet dagger SACB3. Dagger B385, which has slightly below 1 % As, in this respect constitutes an exception. The contents of Ag, Ni and Sb never exceed 0.05 %, so all sampled objects would fall into Metal Group 2 (Cu + As) according to the classification by Pollard *et al.* (2018, pp.85–114). Co and Bi values are also not particularly elevated, with Bi values the higher of the two, in some cases reaching proportions of 0.05 %. Lead contents in the objects are very low, less than 100 ppm, except for the dagger CS8965, which reaches a value of 710 ppm (0.07 %).

The two remaining pieces are made of bronze with low proportions of tin (2.5 % in the dagger CS8980 from Monteagudo and 5.6 % in the dagger without inventory number from San Antón). Both bronzes contain significant proportions of arsenic, around 0.8 % As. These pieces also do not contain any other element in proportions greater than 0.1 %, so they would likewise fall into Metal Group 2 according to Pollard *et al.* (2018, pp.85–114). As the overwhelming majority of copper-base metal objects from EBA south-east Spain fall into this group (Pollard *et al.*, 2018, pp.100–103), this classification does not facilitate regional distinctions within the El Argar culture area.

Stos-Gale (2001) analysed some other pieces from San Antón and Montegudo. They are mostly arsenical coppers, except for a dagger from Monteagudo (MU35) that only has 0.4 % As. The metal strip from San Antón analysed by Stos-Gale (MU29), which consists of a quaternary alloy with Zn, does not belong to the El Argar period. The three-rivet dagger (MU28) differs from the remainder of this assemblage because of its high proportion of silver (0.4 % Ag).

5. Provenance study

Lead isotope analyses carried out on copper ores from the Lower Segura Valley include the ten samples presented here (Table 3) and one previously published by Murillo-Barroso *et al.* (2015, p.151, note 9). All of them plot in the same zone and present a clear linear regression trend in their 207Pb/204Pb versus 206Pb/204Pb ratios (Figure 2), allowing a good definition of their isotopic field, which tends to cover radiogenic zones. They can be clearly differentiated from the trend shown by ores from Cerro Minado in Almería, whose linear regression runs in

Table 3. Lead isotope ratios of copper ores from the Lower Segura Valley (1–10: MC-ICP-MS analyses carried out at the University of Frankfurt [Neptune, Thermo Scientific]; 11: TIMS analysis carried out at the Geochronology and Isotope Geochemistry Research Laboratory of the University of the Basque Country [Finnigan MAT 262, Thermo Scientific]).

No.	Lab Code	Field Sample ID	Provenance	206Pb/204Pb	2SE	207Pb/204Pb	2SE	208Pb/204Pb	2SE	208Pb/206Pb	2SE	207Pb/206Pb	2SE
1	4002/13	ORI-28-2-1	Cabezo de Bello	19.4834	0.0043	15.7060	0.0035	39.3005	0.0097	2.01712	0.00013	0.80612	0.00004
2	4003/13	ORI-30-1-1	Cabezo de Bello	19.0269	0.0012	15.6859	0.0011	39.0653	0.0033	2.05316	0.00007	0.82440	0.00001
3	4005/13	SAN-2-0-7	Cabezo Mal Nombre	18.9327	0.0012	15.6817	0.0011	39.0398	0.0033	2.06203	0.00007	0.82829	0.00002
4	4006/13	SAN-64-5-3	Cerro de la Mina	19.1208	0.0013	15.6902	0.0011	39.1195	0.0034	2.04591	0.00007	0.82058	0.00002
5	4008/13	SAN-16-0-4	Cerro de la Mina	19.9951	0.0031	15.7456	0.0027	39.2817	0.0080	1.96457	0.00016	0.78747	0.00004
6	4009/13	SAN-33-6-1	Cerro de la Mina	19.8671	0.0012	15.7272	0.0010	38.9798	0.0030	1.96203	0.00006	0.79162	0.00002
7	4010/13	SAN-27-5-1	Cerro de la Mina	19.2982	0.0012	15.6958	0.0011	39.2235	0.0030	2.03250	0.00005	0.81333	0.00001
8	4011/13	SAN-14-0-2	Cerro de la Mina	18.7658	0.0016	15.6636	0.0014	38.9227	0.0036	2.07413	0.00006	0.83469	0.00002
9	4012/13	SAN-33-7-2	Cerro de la Mina	19.3334	0.0014	15.7010	0.0011	38.9932	0.0033	2.01688	0.00006	0.81212	0.00002
10	4013/13	SAN-24-2-1	Cerro de la Mina	19.2240	0.0056	15.6881	0.0047	39.1796	0.0120	2.03806	0.00013	0.81607	0.00005
11	PA13535B	—	Cerro de la Mina	19.0975	0.0033	15.6914	0.0031	38.9524	0.0136	2.03960	0.00053	0.82165	0.00005

Table 4. Lead isotope ratios of El Argar copper-base metal objects from the Lower Segura Valley (MC-ICP-MS analyses carried out at the Geochronology and Isotope Geochemistry Research Laboratory of the University of the Basque Country [Neptune, Thermo Scientific]).

Lab Code	Object Category	Museum	Inventory Number	Provenance	Bibliography	206Pb/204Pb	2 SE	207Pb/204Pb	2 SE	208Pb/204Pb	2 SE	208Pb/206Pb	2 SE	207Pb/206Pb	2 SE
8957	halberd	Museo Arqueológico Provincial de Alicante	CS8957	San Antón (?)	Brandherm, 2003, no. 1457A	18.3654	0.0007	15.6419	0.0009	38.4365	0.0035	2.09287	0.00013	0.85170	0.00002
8965	knife-dagger	Museo Arqueológico Provincial de Alicante	CS8965	San Antón	Brandherm, 2003, no. 1257	18.2663	0.0008	15.6352	0.0007	38.4197	0.0020	2.10330	0.00004	0.85596	0.00001
8967	dagger	Museo Arqueológico Provincial de Alicante	CS8967	San Antón (?)	Brandherm, 2003, no. 1502	18.4624	0.0008	15.6573	0.0009	38.5515	0.0037	2.08812	0.00014	0.84807	0.00002
8970	dagger	Museo Arqueológico Provincial de Alicante	CS8970	San Antón	Brandherm, 2003, no. 1501	18.3558	0.0048	15.6702	0.0045	38.5004	0.0115	2.09746	0.00021	0.85370	0.00005
8973	dagger	Museo Arqueológico Provincial de Alicante	CS8973	San Antón	Brandherm, 2003, no. 1232	18.5245	0.0007	15.6667	0.0007	38.7189	0.0019	2.09015	0.00004	0.84573	0.00001
8978	dagger	Museo Arqueológico Provincial de Alicante	CS8978	San Antón	Brandherm, 2003, no. 743	18.4032	0.0032	15.6700	0.0030	38.5509	0.0087	2.09480	0.00021	0.85148	0.00004
8979	dagger	Museo Arqueológico Provincial de Alicante	CS8979	San Antón (?)	Brandherm, 2003, no. 744	18.4589	0.0011	15.6698	0.0014	38.5386	0.0054	2.08781	0.00020	0.84891	0.00004
8980	dagger	Museo Arqueológico Provincial de Alicante	CS8980	Monteagudo	Brandherm, 2003, no. 481	18.5743	0.0009	15.6758	0.0012	38.5437	0.0044	2.07511	0.00016	0.84395	0.00003
B383	axe	Museo Arqueológico Comarcal de Orihuela	B 383	San Antón	Simón García, 1998, fig. 5,1	18.3127	0.0008	15.6675	0.0007	38.5483	0.0020	2.10500	0.00004	0.85555	0.00001
B385	dagger	Museo Arqueológico Comarcal de Orihuela	B 385	San Antón	Brandherm, 2003, no. 585	18.3297	0.0006	15.6456	0.0006	38.4206	0.0019	2.09608	0.00006	0.85357	0.00001
SACB3	dagger	Museo Arqueológico Comarcal de Orihuela	SA (CB) 3	San Antón	Brandherm, 2003, no. 632	18.3157	0.0015	15.6449	0.0014	38.2799	0.0038	2.09000	0.00009	0.85418	0.00002
MUS	dagger	Museo Arqueológico Comarcal de Orihuela	—	San Antón	Brandherm, 2003, no. 699	19.2528	0.0012	15.6875	0.0012	38.9590	0.0043	2.02355	0.00013	0.81482	0.00002

	206Pb/204Pb	2 SD	207Pb/204Pb	2 SD	208Pb/204Pb	2 SD	208Pb/206Pb	2 SD	208Pb/206Pb	2 SD	n
Calibration Standard NBS981	16.9425	0.0035	15.4990	0.0065	36.7177	0.0285	2.16719	0.00131	0.91480	0.00022	4

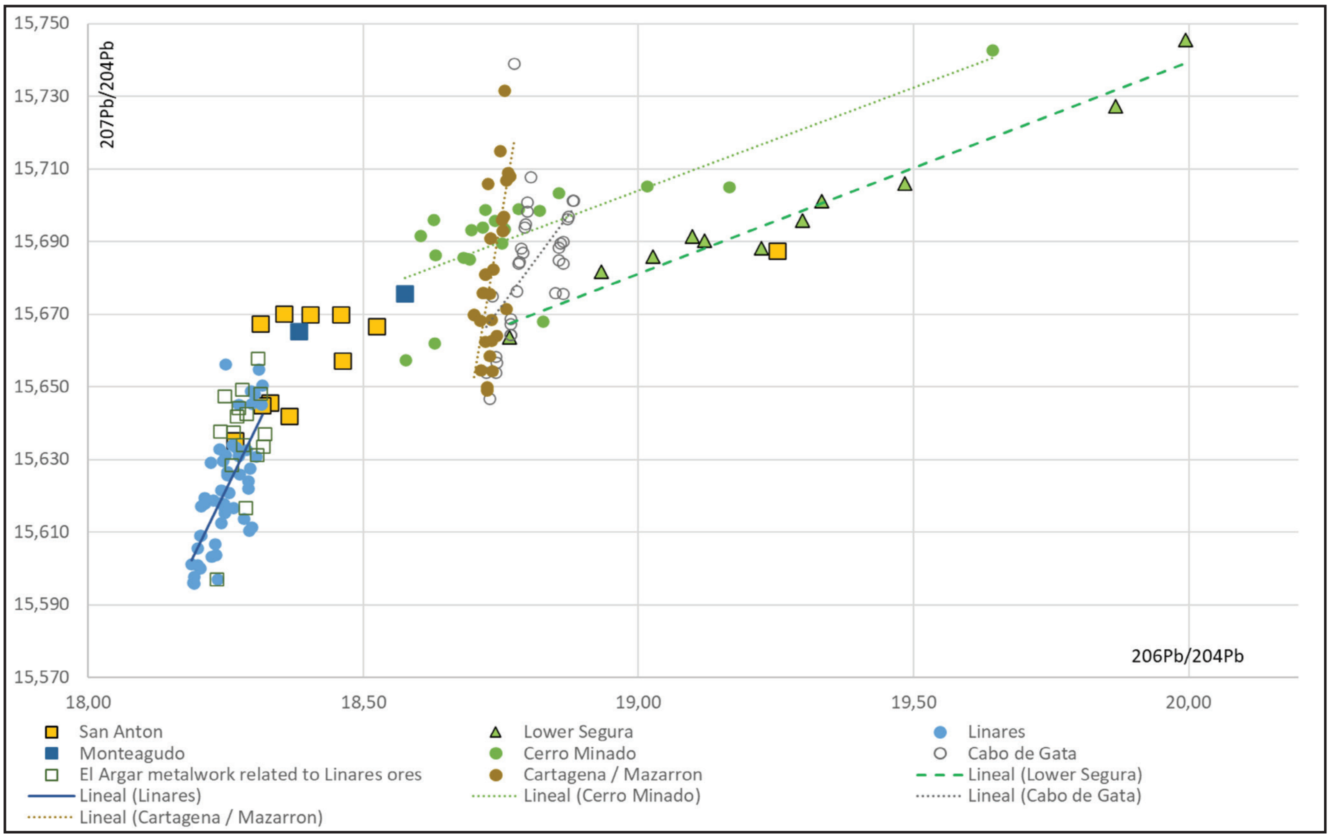

Figure 2. $^{207}Pb/^{204}Pb$ versus $^{206}Pb/^{204}Pb$ lead isotope ratios of El Argar copper-base metal objects from the Lower Segura Valley and the Linares area, and of different ore bodies in south-east Spain.

parallel. The graph shows that these ores are also clearly distinguishable from other mineralisations of the Betic Sierras, such as Cabo de Gata in Almería or those of the Sierras of Cartagena and Mazarrón in Murcia, whose linear-spread trends run perpendicular to that of the Segura Valley ores. They are also isotopically differentiable from the ores of the Linares mining district.

The objects from San Antón and Monteagudo analysed for their lead isotope ratios include the 12 samples presented here (11 from San Antón and 1 from Monteagudo; Table 4) and a dagger blade from Monteguado whose analysis was published by Stos-Gale (2001, table 2, MU32) and which is included in the OXALID database. The results shown in Figure 2 demonstrate that only one of the analysed objects can be related to the ores of the Segura Valley; it is the dagger blade without inventory number from the Orihuela Museum which is made of bronze (5.6 % Sn and 0.8 % As). From a compositional point of view, this moderate amount of arsenic is compatible with that detected in the local ores, as are the very low proportions of other trace elements. The rest of the analysed objects, consisting of arsenical copper with high proportions of arsenic, plot in different zones of the graph that do not coincide with ores from either Cerro Minado or the Cartagena and Mazarrón mines. Two of them (looking at all plotted combinations) fall into the isotopic field of Linares (CS8965 knife-dagger and B385 two-rivet dagger from San Antón). The majority, including the two pieces from Monteagudo, must be related to different ore bodies, either from the provinces of Granada or Málaga or from the Cordovan area of Los Pedroches and adjacent parts of the Sierra Morena.

If we include all El Argar copper-base metal objects whose lead isotope ratios have been published or are in the process of being published (Montero Ruiz *et al.*, forthcoming) in the comparison (73 objects), we observe that another piece fits within the isotopic field of the Segura Valley ores (Figures 3 and 4). It is a bronze dagger (8.7 % Sn and 0.1 % As) from grave 21 of Cerro de la Encina (Granada), and this possibility was already highlighted when the respective analysis was first published (Murillo-Barroso *et al.*, 2015, p.150), now confirmed with a greater number of ore samples to define the isotopic field.

Currently, there are 16 EBA metalwork objects in the available corpus of lead isotope analyses that can be linked to the Linares ores, plus the two objects identified in the present study, which represents 21 % of the El Argar copper-base metal objects analysed so far. The plotted spread of the lead isotope analyses suggests that the ore bodies from which the metal used in the manufacture of El Argar objects was extracted were diverse. Some of these ore bodies, such as those found in the coastal ranges of Murcia and Almería, were of limited significance: the mines of the Lower Segura Valley (only 2 of the 85 objects analysed), Cerro Minado (4 objects, one of them found in grave 21 of Cerro de La

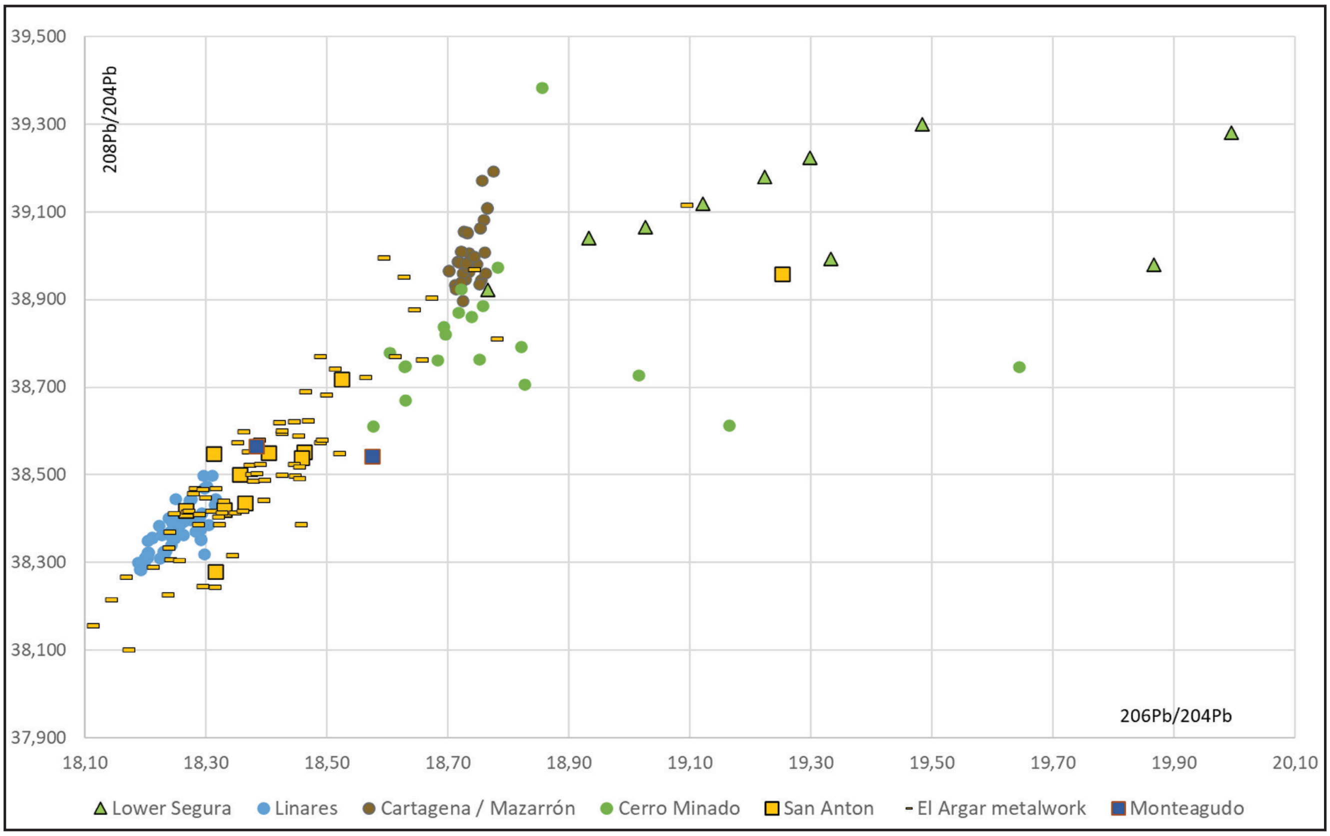

Figure 3. $^{208}Pb/^{204}Pb$ versus $^{206}Pb/^{204}Pb$ lead isotope ratios of El Argar copper-base metal objects and of different ore bodies in south-east Spain.

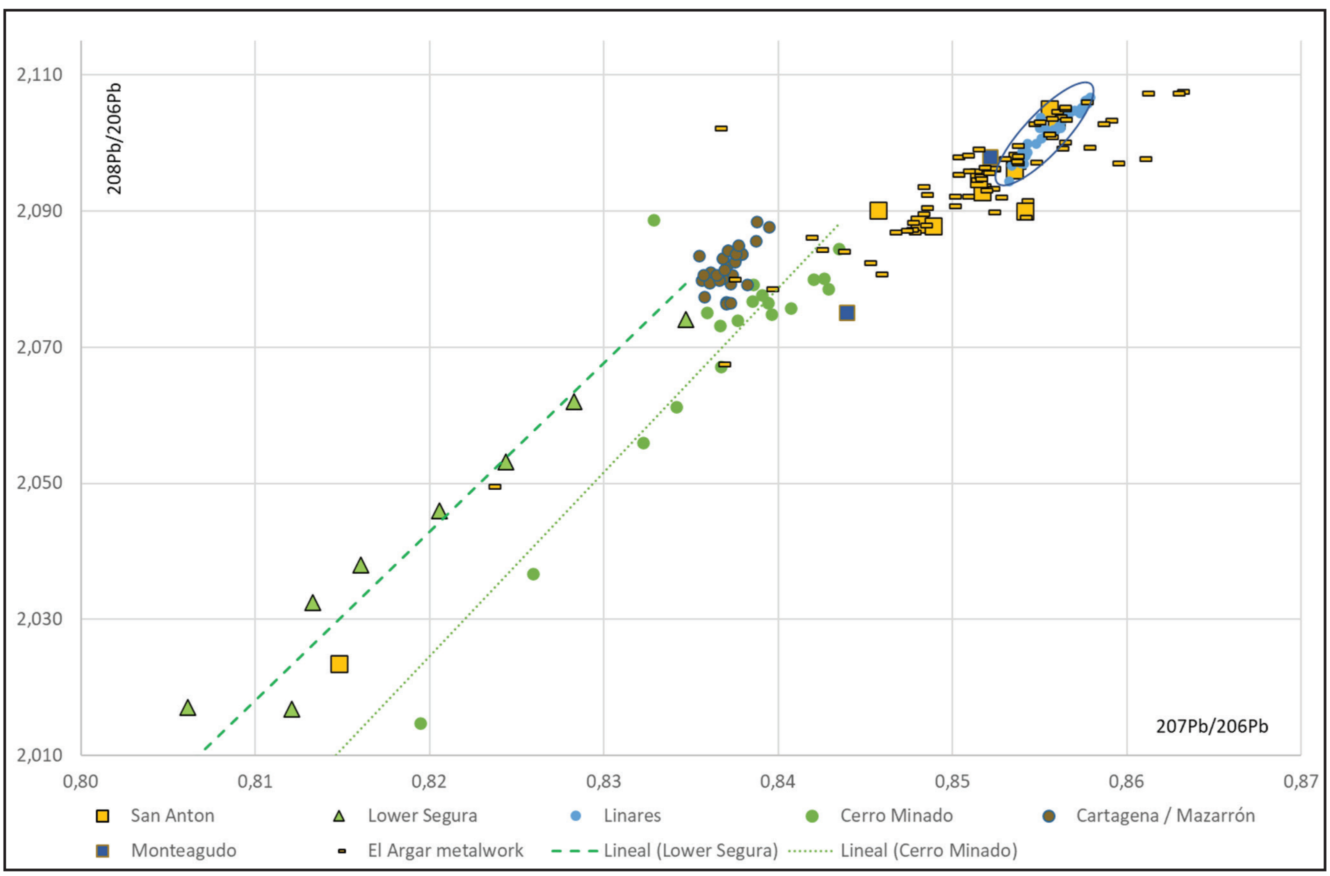

Figure 4. $^{208}Pb/^{206}Pb$ versus $^{207}Pb/^{206}Pb$ lead isotope ratios of El Argar copper-base metal objects and of different ore bodies in south-east Spain.

Encina, although this metal could also be from the Alcolea mines in Almería) and Mazarrón (1 object).

At the same time, the plotted spread of the analyses indicates that metal from different ore bodies circulated throughout the El Argar culture area, regardless of their geographical location. Thus, a dagger blade from Cerro de la Encina can be related to ores from Murcia and a bracelet from the same context to ores from Almería, and only a small part of the objects from El Argar, Monteagudo or San Antón were manufactured using metal of local origin. Metal produced from ores of the Linares mining district has been found at a number of different sites across the El Argar culture area, but based on present evidence it does not account for a majority of the metal used, neither with regard to the overall body of analysed El Argar copper-base metalwork nor regarding any of the sites where we have a minimum of five objects analysed. Finally, taking into account the latest available data (Murillo-Barroso *et al.*, 2015; Montero Ruiz *et al.*, forthcoming) it is possible to identify metal from outside the El Argar culture area, originating from Los Pedroches or from geographically even more remote regions, such as northern Iberia and the Alps, and this wide catchment partly explains the diversity of raw material sources apparent in the lead isotope data.

6. Conclusions

The results from the programme of metal analyses presented here clearly demonstrate that the majority of copper-base metal objects in circulation in the Lower Segura Valley during the EBA do not seem to have been made from locally available copper ores. Another important result is that only a minority of objects were possibly made from ores originating from the Linares mining district. Instead, the raw material used in the production of most EBA copper-base metal objects from the Lower Segura Valley appears to have come from sources further afield, most likely ore bodies in the provinces of Granada, Málaga or Córdoba, *i.e.* regions either on the periphery of the El Argar culture area or entirely beyond its confines. This observed variation in raw material sources for EBA copper-base metal objects is consistent with results from previous programmes of metal analyses focusing on other regions of south-east Spain during the El Argar period, although a considerably larger dataset would be required in order to make statistically valid statements about the relative proportion of metal supplied by different source areas.

In any case, the variation in raw-material make-up observed in the presently available dataset lends further support to the notion that metal recycling, which could be expected to exercise a homogenising effect on metal composition and lead isotope ratios, did not play a significant part in supplying El Argar society with copper-base metal (*cf.* Montero Ruiz *et al.*, 2020, pp.242–245). As we have no indication of long-distance movement of ores, and as metal travelling as ingots from the Linares mining district only seems to have accounted for a minority of the metal consumed by El Argar society (*cf.* Moreno Onorato and Contreras Cortés, 2010), it would seem to have been mostly finished objects that travelled, sometimes over considerable distances, from their place of manufacture to where they were deposited in the archaeological record.

What the results from our programme of analyses do not support then is a model of centralised metal procurement and supply for the El Argar culture area. Things were clearly more complex than the prevalent model of tight political control over metalwork production exercised at polity level would have it. It is, of course, entirely possible to envisage other models involving a high level of élite control over metalwork production that do not rely on directly controlling raw material supply, but which instead focus on the social and symbolic connotations of metalwork. Such models, however, will require us to look beyond what metal analyses alone can tell us and consider other elements of the social and economic context in which metal objects were produced and consumed (*cf.* Brandherm, 2009, pp.176–179; Lull Santiago *et al.*, 2010b, pp.24–26).

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