Los Callejones: a Roman Republican iron mining and smelting centre in the south east of the Iberian Peninsula

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ABSTRACT: An iron mining and smelting site dated of the Roman Republican period (1st century BC) has been recently discovered in Almería province, Spain. Archaeometallurgical remains consist of iron ore, smelting and smithing slags, furnace lining fragments and iron blooms. Analyses have been performed using SEM/EDAX and optical microscopy. The ore was very pure goethite. Tapped slags are fayalite-type also containing calcium and manganese, produced in small shaft furnaces of about 500mm in diameter. Calcium-rich sand was used as flux. Analytical results are reviewed in the light of late Iron Age and early Roman iron technology.

Introduction

The archaeological site of Los Callejones is located in the upper basin of the Almanzora River (Almería, Spain), a region of the south east of the Iberian Peninsula. It was discovered a few years ago during the fieldwork project *Estudio del proceso histórico durante la Prehistoria y la Antigüedad en la cuenca del Alto Almanzora (Almería)* [Study of the historical process through Prehistory and Antiquity in the basin of the upper Almanzora River, Almería'], authorized and funded by the Consejería de Cultura de la Junta de Andalucía (Martínez Padilla *et al* 1997; Román Diaz *et al* 1999; López-Medina *et al* 2001) and *Poblamiento y territorio en la cuenca del Alto Almanzora desde la Prehistoria a la época Medieval: transformaciones y pervivencias* [Settlement and territory in the upper Almanzora River basin from prehistory to medieval times: transformations and survivals], funded by the Ministerio de Ciencia y Tecnología (BHA2000-1228), and carried out under the direction of Catalina Martínez Padilla.

Its situation in a mountain landscape (Fig 1) is within the Sierra de los Filabres, which form a part of one of the complex of Bética Ranges called Nevado-Filábride, which are made up of limestone, degraded slate, schist, quartzite rocks and tectonic breccia of Upper Triassic age. The area offers plentiful and varied natural resources which have been favourable for human settlement since prehistory. To the existence of water sources, woods, hunting and rich grazing, several outcrops of easily-worked, high-grade copper and iron ores must be added. Toponyms such as Las Herrerías ('blacksmiths' workshops), Las Menas ('the ores') and Barranco del Hierro ('iron gully') — this last close to Los Callejones, reflect this. The hill from which the archaeological site takes its name is formed by limestone ridges cut by impressive cliffs (Fig 2). The top is at 1,215m above sea level and 200m above the Barranco del Hierro. Archaeological evidence, archaeometall-urgical analysis and thermoluminiscence dating indicate it is a place of mining and metallurgical activity dated to the 1st century BC.

However, this is not the earliest evidence for iron making in the area of the Upper Almanzora. Indications of this activity (ore fragments, slags and iron implements) have been found in almost all the sites belonging to the Iberian Culture (7th–2nd century BC).

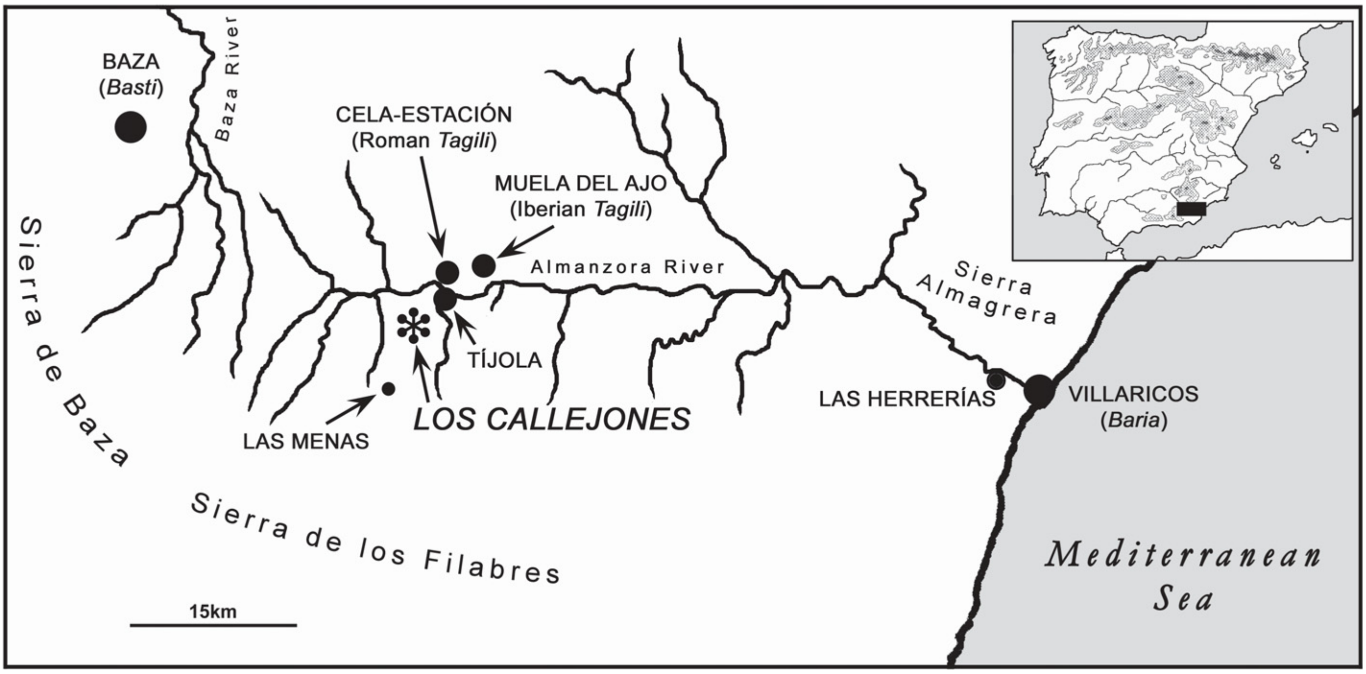

Figure 1: Map showing the location of Los Callejones and other places mentioned in the text.

Among them the *oppidum* at La Muela del Ajo (the Iberian *Tagili*) stands out. This is the largest Iberian site in the area, covering 70,000m^2 (López-Medina 1997, 203–5, 223, 345–6; Román-Díaz *et al* 1999, 11). Its excellent position made it possible to exploit an extensive and fertile plain for farming. In addition, it is located on one of the most important overland routes of the South East, the valley of the Almanzora River, which connected the coastal cities (like the Phoenician *Baria*) and others in the interior (like *Basti*, the nearest Iberian *oppidum*). The evidence from the site of iron ore and slags suggests that the Iberian people must have obtained and worked this metal to supply the growing local need for tools, weapons and other iron implements.

Roman domination from 209 BC, after the Second Punic War, involved the integration of these territories into a new administrative division: the province of *Hispania Ulterior*. There are no traces of confrontation or resistance to the Roman army by the local communities which, as the Latin literary sources state (Livy: *Ab urbe condita*, XXVIII; Orosius: *Adversum paganos*, IV, 18, 7), after conquering *Baria* passed quickly and without any setback to upper Andalusia and the Guadalquivir valley following the route of the Almanzora River. As the population gave itself up to the Roman power *in deditio*, it obtained the legal status of *civitas stipendiaria*. The territory was considered as *ager stipendiarius*, which obliged it to pay tributes or taxes in exchange for some kind of autonomy to take local decisions. Changes in the settlement pattern can be observed at this time, with the abandonment in the 2nd-1st century BC of La Muela del Ajo and its relocation to Cela-Estacion de Tíjola (Roman *Tagili*).

In this process of local change, the mining exploitation at Los Callejones is of great interest. Two mine entrances about 300m apart, a well-built path to the mines, and a large platform 30m above the mining area have been recorded by the archaeological survey. Remains of walls, many pottery fragments (Roman Campanian C, Roman Republican amphora, painted pottery of indigenous tradition and coarse wares) and abundant metallurgical debris (ore, slags, pieces of furnace/hearth lining) can be seen on the platform surface, which define the function of the site quite well. Thermoluminescence dating performed at the Laboratorio de Datación y Radioquímica of the Universidad Autónoma de Madrid of one selected ceramic sherd gave a date of 1982 ± 198 BP which has confirmed the dating of the site to the 1st century BC.

This mining activity indicates the beginning of intensification of iron production at this time, a fact corroborated by the frequent finds of slags and iron objects in Imperial Roman and medieval sites. In the beginning, Los Callejones probably supplied metal to make the iron tools necessary for building the new Roman city of *Tagili*, or for working the important lead and silver mines of Sierra Almagrera and Las Herrerías, near the mouth of the Almanzora River. It is likely that production at Los Callejones was controlled from *Tagili*, the principal city in the area, if the mines were within its *ager stipendiaria*, but it is also possible that they were

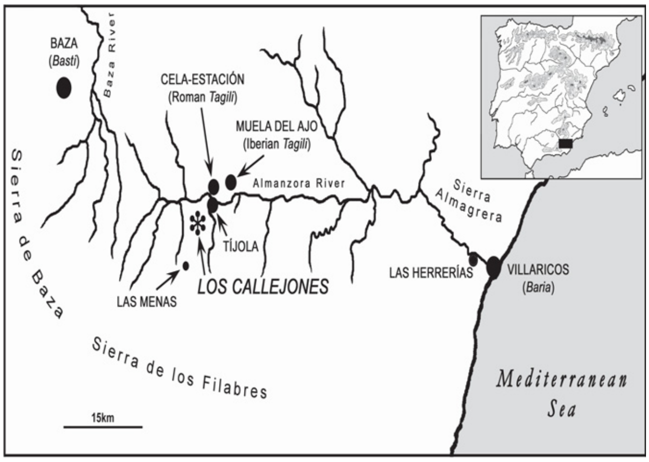

Figure 2: The landscape of Los Callejones, looking south.

worked under the direct control of a Roman businessman. Domergue (1990, 234–236) describes several kinds of mine owners, taking into account circumstances such as the degree of state pressure or the dynamism of businessmen coming from Italy.

The archaeometallurgical materials

The mines are sited in the lower part of a small valley between impressive cliffs (see Fig 2). Their interior has not been explored because of the difficulty of entering the first section of the gallery. Near the mouths, among the spoil heaps it is easy to find beautiful well-crystallized goethite (iron hydroxide, FeO.OH) fragments, surely the main iron ore worked. The spoil heaps are quite small, suggesting the mines were exhausted in a few years. This is corroborated by the significant archaeological pottery, almost all dated to the Roman Republican period. Only a few sherds of medieval pottery have been found, which are interpreted as a consequence of the sporadic presence of Arabs on the site, but without any evidence of new work in the mines.

The smelting area was placed on the flat top of a ridge that is difficult to climb, about 7,500m^2 in area (see Fig 2)The stone foundations of walls of buildings can be seen but more astonishing is the large amount of tap slag fragments covering the ground (Fig 3); slags were also thrown into the neighbouring gullies. Due to the great dispersion of the slags it is not easy to estimate its total amount which does not seem to be greater than 40–50 metric tons.

The soil has been much eroded. Hence valuable archaeological deposits are now missing and the bare rock appears at many places on the surface. The remains of smelting furnaces are restricted to some fragments of lining and stones with signs of thermal alteration (burnt or vitrified surfaces). The curvatures of some lining fragments allow us to calculate a furnace diameter of about 0.4–0.5m. We can assume that small shaft furnaces built with stones, lined with clay and provided with a tapping-hole were used to smelt the iron ores.

Figure 3: Slag fragments on the surface of the smelting area of Los Callejones. The scale bar is 2m.

The erosive process has deeply altered the soil. Consequently, a valuable archaeological deposit is lacking at the present time and bare rock appears at many places on the surface. The remains of smelting furnaces are restricted to some fragments of lining and some stones with signs of thermal alteration (burnt or vitrified surfaces). The curvatures of some lining fragments allow us to calculate the furnace diameter of about 0.4–0.5m. Given the available evidence, we can assume that small shaft furnaces built with stones, lined with clay and provided with a tapping-hole were used to smelt the iron ores.

The find of a plano-convex slag cake of about 0.3m in diameter, typical of a smithing hearth bottom (Fig 4), is

Figure 4: Smithing slag cake from Los Callejones.

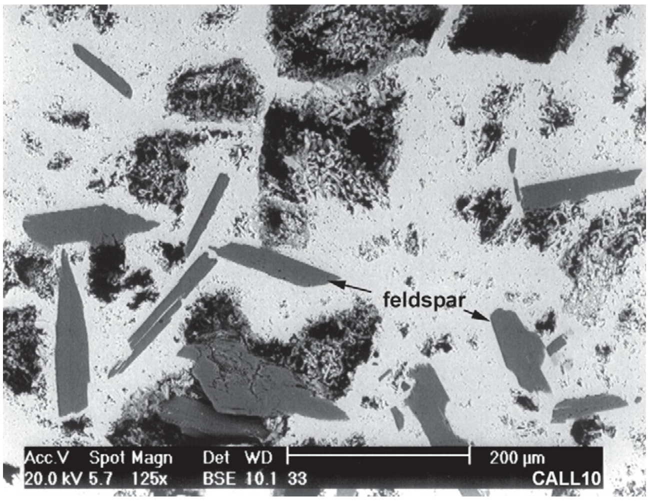

Figure 5: Back-scattered SEM image of iron ore from Los Callejones. The dark, irregular areas are voids.

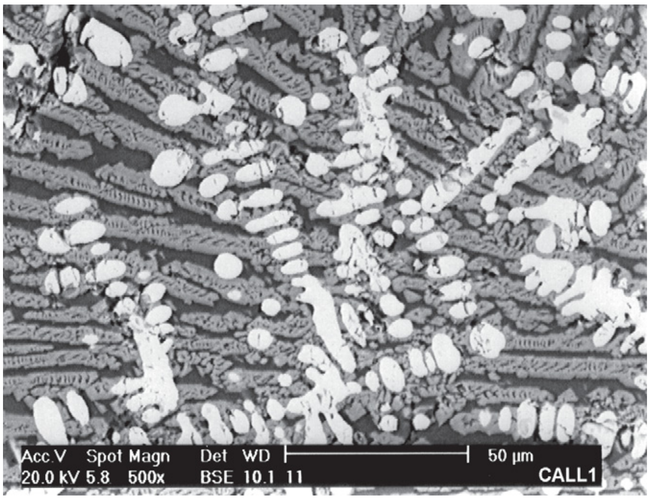

Figure 6: Back-scattered SEM image of A-type tap slag from Los Callejones. Fayalite (grey), glassy matrix (dark grey) and dendritic wüstite (white) are visible.

a good evidence that the blooms made in the shaft furnaces were hot-hammered on site to produce iron ingots. A small bloom has been recovered and analysed.

Analytical results

Experimental procedures

Binocular and optical microscopy was used to determine the macroscopical and microscopical features of the samples (colour, texture, streak, porosity, etc), and SEM-EDS for observation and analysis of the different phases in the samples. Quantitative analysis was performed by XRF-EDS using the EDAX DX4i electron micro-analyser on the Philips XL30 SEM. Bulk analysis of each sample represents the mean values of four analyses made by scanning different representative windows at 100x magnification. All the samples for analysis were set in resin, polished as for metallography, and coated with gold.

Iron ores

Four samples of goethite picked from different points on the mine spoil heaps were analysed to determine their chemical composition; the results are shown in Table 1. They are usually iron-rich ores containing about 95% iron oxide, analysed as FeO. The remaining 5% gangue is usually feldspar (Fig 5).

Smelting slags

Two types of slags can be distinguished at naked eye: A) typical tap slags, dark-brown or almost black in colour, sometimes exhibiting surface oxidation of dark-grey colour, dense and with low porosity, and B) glassy slags similar to deep grey-green bottle glass, with conchoidal fracture and no porosity. They are very scarce and confined to one place in the smelting area.

Seven samples of A-type tap slags have been analysed; the results are shown in Table 2. As the slags are not at all or only slightly magnetic, the iron total has been expressed as FeO. All samples are well-structured fayalitic slags (Fig 6). Besides silica and iron oxide, the fayalite normally contains noticeable amounts of calcium and manganese. Dendritic wüstite containing a

Table 1: Chemical composition of iron ore from Los Callejones

		Composition (wt%)								
Analysis No.	Phase	MgO	Al_2O_3	SiO_2	K_2O	TiO_2	CaO	MnO	FeO	SO
CALL-09/1	Bulk analysis	0.46	0.43	1.37	0.12	0.28	0.35	1.52	95.0	0.47
CALL-10/1	Black stick (feldspar)	2.28	30.50	50.3	12.10	0.70	0.59	0.32	2.77	0.42
CALL-10/2	Matrix	0.42	0.67	1.80	0.24	0.54	0.35	0.45	95.2	0.36
CALL-10/3	Bulk analysis	1.20	7.74	7.89	1.03	0.00	0.27	0.69	80.9	0.24
CALL-11/1	Bulk analysis	0.00	0.31	1.89	0.18	0.14	0.34	1.35	95.5	0.27
CALL-13/1	Black stick (feldspar)	2.67	28.30	51.0	13.60	1.06	0.25	0.48	2.32	0.38
CALL-13/2	Matrix	0.00	0.00	1.59	0.22	0.38	0.44	1.29	95.9	0.20
CALL-13/3	Bulk analysis	0.00	1.06	3.78	0.48	0.48	0.36	1.14	92.3	0.39

Table 2: Chemical composition of tap slags from Los Callejones

		Composition (wt%)							
Analysis No.	Phase	MgO	Al_2O_3	SiO_2	K_2O	TiO_2	CaO	MnO	FeO
CALL-01/1	Glassy matrix	0.74	16.50	33.3	8.44	0.83	13.40	1.46	25.3
CALL-01/2	Fayalite	0.98	1.17	24.7	0.98	0.38	13.70	3.65	54.5
CALL-01/3	Bulk analysis	0.82	5.44	19.1	2.03	0.48	7.81	2.86	60.1
CALL-02/1	Fayalite	0.82	5.44	19.1	2.03	0.45	7.81	2.86	61.1
CALL-02/2	Fayalite	0.90	7.15	29.8	3.81	0.58	10.60	3.61	43.4
CALL-02/3	Glassy matrix	0.82	8.32	29.1	4.47	0.37	13.60	2.96	39.8
CALL-02/4	Wüstite	0.54	0.43	0.62	0.30	0.53	0.38	1.59	95.3
CALL-02/5	Bulk analysis	0.93	5.75	20.5	2.28	0.66	7.14	2.21	60.2
CALL-03/1	Fayalite	1.11	6.51	28.5	3.14	0.78	13.20	3.53	42.8
CALL-03/2	Glassy matrix	0.28	7.52	32.5	4.73	0.79	16.90	2.58	34.5
CALL-03/3	Wüstite	1.18	0.96	0.85	0.19	0.60	0.66	2.30	93.1
CALL-03/4	Bulk analysis	0.84	4.53	21.4	2.66	0.71	9.87	2.37	57.3
CALL-04/1	Glassy matrix	0.53	13.60	31.8	5.81	0.97	15.40	1.28	30.2
CALL-04/2	Fayalite	0.99	0.77	23.7	0.40	0.34	6.01	4.51	62.9
CALL-04/3	Wüstite	0.00	0.66	1.05	0.24	0.83	0.50	1.10	95.4
CALL-04/4	Bulk analysis	0.55	5.74	22.5	2.25	0.57	7.59	2.57	58.0
CALL-14/1	Fayalite	1.08	5.31	29.8	3.21	0.46	12.80	1.95	45.1
CALL-14/2	Matrix	0.79	11.00	34.0	5.07	0.75	15.80	1.21	31.1
CALL-14/3	Wüstite	0.00	0.54	0.54	0.15	0.30	0.29	0.93	97.1
CALL-14/4	Bulk analysis	0.27	4.80	14.6	1.41	0.51	5.83	1.64	70.8
CALL-15/1	Glassy matrix	0.37	14.90	33.9	5.64	0.34	16.10	0.86	27.8
CALL-15/2	Fayalite	2.52	0.53	24.7	0.11	0.16	2.66	3.12	66.1
CALL-15/3	Wüstite	0.00	1.74	2.15	0.45	0.85	0.68	1.13	93.0
CALL-15/4	Bulk analysis	0.90	7.20	22.2	2.50	0.48	6.47	2.03	58.0
CALL-16/1	Matrix	1.38	8.46	32.6	3.21	0.18	14.50	3.05	36.3
CALL-16/2	Wüstite	0.86	0.63	1.91	0.59	0.95	1.19	1.97	91.7
CALL-16/3	Bulk analysis	0.89	7.36	25.6	2.94	0.42	10.00	2.42	50.0

Note: Phosphorus and sodium concentrations were below their limits of detection in these analyses

small amount of manganese is usually abundant. When the bulk compositions of the slags are plotted on the $FeO-SiO_2-CaO$ ternary diagram, it can be observed that the points fall in the olivine (fayalite) region (Fig 7), with free-running temperatures of 1100–1150°C.

The B-type glassy slags have a chemical composition and appearance quite different from the A-type. The glassy matrix is very homogeneous (Table 3). The iron content is dramatically low (3–6% FeO) while calcium, silicon, aluminium and manganese have high values. Part of the iron is in the metallic state, present as microscopic droplets with diameters of 5–15μm. In the ternary diagram these compositions fall in the region of pseudowollastonite (see Fig 7). Such slags are probably the result of an unsuccessful smelting process, or they could be formed in a zone of the furnace where the charge was only the flux added to the ore in order to get slag. This second option looks more likely, as will be shown later.

The bloom

A small mass of iron, slag and iron oxide and chloride was found during the fieldwork. The slag composition (Table 4) matches quite well with the tap slag data in Table 2. Thus, there is little doubt that the bloom is a local product. The metal is ferritic iron without any sign of carburization, as metallography demonstrates; Figure 8 shows the appearance of a section in the SEM.

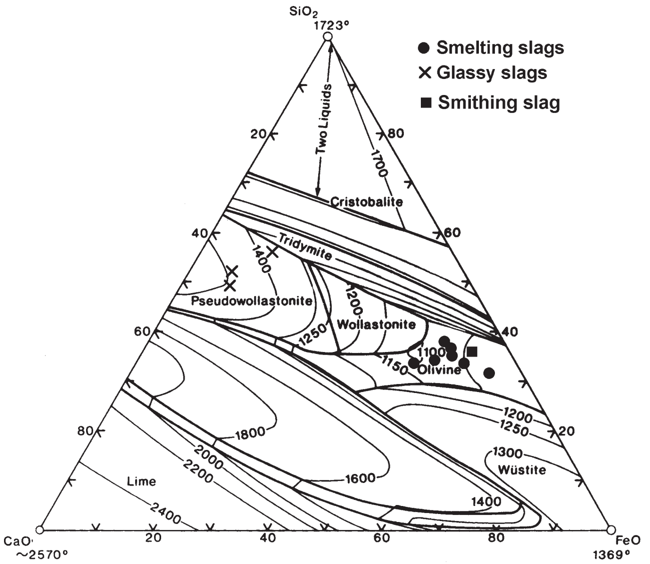

Fig 7: Composition of the slags from Los Callejones on the FeO-SiO_2-CaO equilibrium ternary diagram.

Smithing slags

The analysis of one sample removed from a big cake of slag formed in the bottom of a smithing hearth shows a chemical composition similar to the tapped slags (Table 5 and Fig 7).

The smelting process

Despite the fact that no furnace structure is preserved, the remains (burnt stones, lining fragments and slags) indicate that shaft furnaces of about 0.5m in diameter were used to smelt the iron ores. No tuyère fragments were among the materials recovered during the survey so the nature of the airflow into the furnace is unknown. It is possible that it could have been provided by natural draught as the wind usually blows almost constantly on the top of the hill where the smelting site is located.

The charge of the furnace would be made up of fuel, goethite and flux. The comparison of the mean chemical compositions of ore and slag indicates that such a flux contained SiO_2, Al_2O_3, K_2O, CaO and MnO, the tap-slag:ore ratio for these oxides being 5.1, 2.6, 5.3, 23.7 and 1.9 respectively.

Turning now to the glassy slags, the glassy-slag:ore ratios for the same oxides are 11.0, 3.7, 12.4, 98.2 and 6.2. If compared with the tap-slag/ore ratios, they are roughly twice as high, except for the CaO which is much higher. Therefore, it is highly probable that a material with the composition of the glassy slags could furnish the oxides needed for producing the normal tap slags during the smelting process. Although these simple arithmetic calculations are a crude approach to the thermodynamic and chemical reactions occurred in the furnace, the composition of the glassy slags do suggest the composition of the fluxes that were added. Figure 9 shows graphically how the tapped slags occupy an intermediate position between the ores and the glassy

Table 3: Chemical composition of glassy slags from Los Callejones

		Composition (wt%)							
Analysis No.	Phase	MgO	Al_2O_3	SiO_2	K_2O	TiO_2	CaO	MnO	FeO
CALL-05/2	Glassy matrix	1.87	7.58	36.8	5.54	0.73	37.0	7.25	3.07
CALL-05/3	Bulk analysis	1.77	7.83	35.6	5.55	1.07	36.7	7.48	3.56
CALL-06/2	Crystals	2.61	16.10	38.8	5.13	0.83	23.6	7.01	5.75
CALL-06/3	Glassy matrix	2.16	9.33	41.1	6.34	1.47	25.7	7.55	5.23
CALL-06/4	Bulk analysis	2.31	9.00	40.3	6.62	1.07	25.6	8.43	6.39
CALL-07/2	Glassy matrix	3.38	9.28	39.5	4.97	1.02	34.7	5.54	2.33
CALL-07/3	Bulk analysis	1.73	9.29	39.2	4.68	1.06	34.9	6.15	2.68

Note: Phosphorus and sodium concentrations were below their limits of detection in these analyses

Table 4: Chemical composition of the slag trapped in a bloom from Los Callejones

		Composition (wt%)							
Analysis No.	Phase	MgO	Al_2O_3	SiO_2	K_2O	TiO_2	CaO	MnO	FeO
CALL-12/1	Fayalite	3.11	0.82	25.8	0.58	0.36	0.83	12.10	56.3
CALL-12/2	Glassy matrix	0.35	14.00	31.0	3.58	1.81	13.20	3.06	32.6

Note: Phosphorus and sodium concentrations were below their limits of detection in these analyses

Table 5: Chemical composition of smithing slag from Los Callejones

		Composition (wt%)							
Analysis No.	Phase	MgO	Al_2O_3	SiO_2	K_2O	TiO_2	CaO	MnO	FeO
CALL-8/1	Glassy matrix	0.15	19.00	34.0	6.77	0.96	15.10	0.84	22.9
CALL-8/2	Fayalite	1.51	0.64	25.1	0.20	0.33	9.81	2.40	59.6
CALL-8/3	Wüstite	0.52	0.71	0.72	0.30	0.85	0.47	1.07	95.1
CALL-8/4	Bulk analysis	1.06	6.11	16.9	1.20	0.85	6.04	1.84	65.7

Note: Phosphorus and sodium concentrations were below their limits of detection in these analyses

slags. Calcium may enter the slag from flux, lining, furnace wall (when limestone blocks are used to build it) and ashes; however, given the amounts in Table 2, the majority is likely to have come from flux. Material usable as flux, calcium-enriched silica sand, is not unusual in the geological context of the area; as has been said before, the rocky landscape is made up of silicates (quartzite, schist and slate) and carbonates (limestone). Wind and rainwater erosion have created alluvial deposits in the neighbouring gullies where this kind of sand could easily be found.

Conclusions

The knowledge we have on the technology of iron smelting dated to the Roman Republican period in the Iberian Peninsula and, generally, in the territories where Roman influence spread over Europe in the 1st century BC, is not too very precise. This makes Los Callejones a site of great interest since in a relative small area we can study the mines and, close to them, the remains of iron smelting and working.

Most of the smelting furnaces dated to the Spanish Iron Age seems to be small bowl or shaft furnaces with slag pit. This has been deduced more from the finds of plano-convex slag cakes measuring 200–250mm in diameter, formed in the base of the furnace, than from direct evidence of surviving structures (see a complete catalogue and review of the archaeological finds in Gómez Ramos 1999).

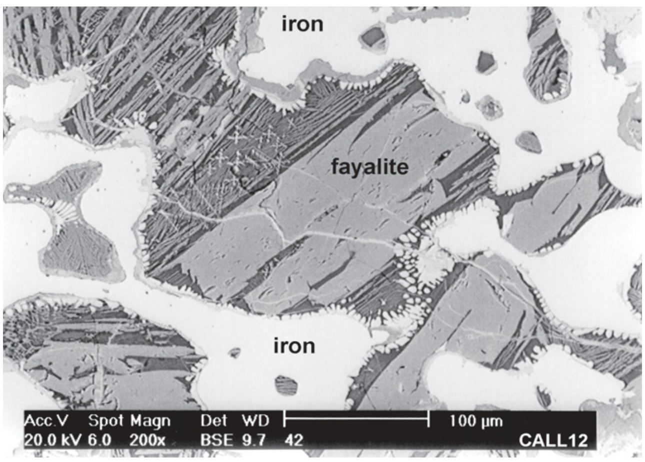

Fig 8: Back-scattered SEM image of iron bloom from Los Callejones showing entrapped fayalite slag.

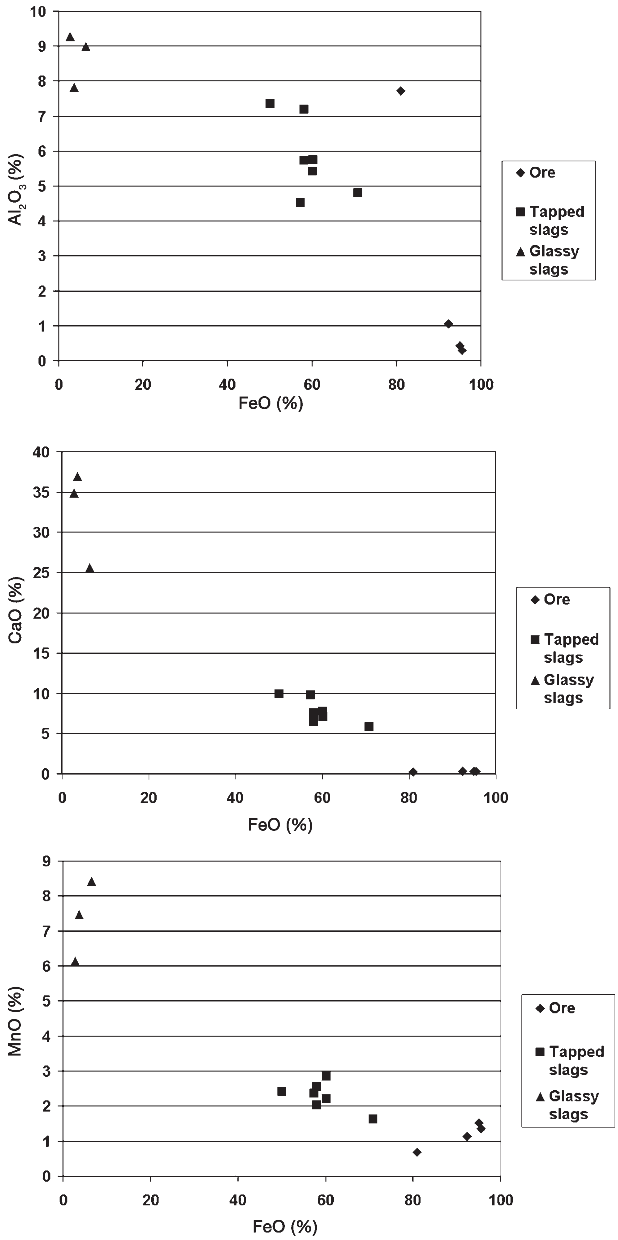

Fig 9: Partial composition of ore and slags from Los Callejones. Note the intermediate position of the tap slags between ores and glassy slags (fluxes).

Late in the Iron Age tapped slags started to appear, indicating that the knowledge of new furnaces with a tapping hole had arrived in some territories, mainly in the southern half of Spain. By the same period similar changes were occurring in England (Hodgkinson and Tebutt 1985). A Spanish example is the Second Iron Age site of Castrejón de Capote (Higuera la Real, Badajoz), where both furnace types have been recorded (Gómez-Ramos 1999, 152–157). The tapped slags are fayalite type, low in calcium.

Closer to the period we are dealing with is Aliseda (Cáceres), where several occupation phases spanning the 9th–1st centuries BC have been documented (Rodríguez-Díaz and Pavón 1999, 104). In the Oriental-influence phase (650–400 BC) there was some metallurgical activity, demonstrated by furnace slags that were heterogeneous in composition, containing abundant unreacted silica, characteristic of simple furnaces charged with incorrect ratios of ore to flux (Rovira and Gómez-Ramos 1999, 220–222). After about 300 years of abandonment, Roman people settled Aliseda again in the 1st century BC. From this last period, contemporary with Los Callejones, several tapped slags and one bloom have been analysed. The slags contain large amounts of wüstite (about 70% FeO total), differing from those from Los Callejones and suggesting that a less efficient smelting process, which caused high iron retention in the slag, was performed there (Rovira and Gómez-Ramos 1999, 223–227).

Technological differences between the pre-Roman and the Roman world are also detected in the Moncayo region of the Ebro valley. The slags recovered at the site of Sierra de Toranzo, dated to the end of the Iron Age (pre-Roman), are of fayalite type, formed in the furnaces from smelting goethite containing silica gangue (Sanz-Pérez *et al* 2001, 51–52). According to these authors, the ore was self-fluxing so no flux addition to the charge was needed. Further afield, at Populonia (Italy), fluxing was not used in the Etruscan iron works, and non-tapping and tapping furnaces were in use at the same time (Benvenuti *et al* 2000, 73).

Local mineralogy plays a determinative role in slag composition, even when the Roman technology was established in the large mining and metal producing centres, as can be deduced from the comparative studies of Roman slags from the Pyrite Belt (Huelva) and Plasenzuela (Cáceres) (Schmidt *et a*l 1999, 236–237) or from the English sites in the East Midlands (Schrüfer-Kolb 1999, 233). Such comparative studies make evident that the chemical composition usually varies from one place to another, and the iron retention in the slag (and therefore the smelting efficiency) is significantly variable. These differences are by no means worrying and are probably meaningless, since they are conditioned both by the nature of the iron ores and the fluxes used, the composition of which usually varies, and the way the smelters applied their knowledge to optimize the exploitation of resources. What must be noted is that technological level can be deduced from local archaeometallurgical studies. It is evident that change took place with the presence of the Romans in the indigenous communities. Iron technology at Los Callejones is a useful example of such change since it occurred in the early stage of Roman domination of Iberian communities in the south east of Spain.

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