

SULPHIDE AND SULPHOSALT MINERALOGY AND PARAGENESIS FROM THE SIERRA ALMAGRERA VEINS, BETIC CORDILLERA (SE SPAIN)

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ABSTRACT

The Sierra Almagrera vein-type mineralization contains base metal sulphides and Pb-Sb-Cu-Ag sulphosalts. The sulphides possess significant proportions of Ag, Sb (galena), Fe (sphalerite) and Sb, Zn (chalcopyrite). Ore microscopy and electron microprobe have revealed a mineralogical and textural variation and confirmed the presence of bournonite, boulangerite and anomalous tetrahedrite. The average sulphosalt formulas are bournonite $Cu_{0.98} Pb_{0.96} Sb_{0.98} S_{3.04}$, boulangerite $Pb_{4.8} Sb_{3.8} S_{11.34}$ and anomalous tetrahedrite $Ag_{0.6} Cu_{9.7} Zn_{3.6} Fe_{0.44} Sb_{3.47} S_{13}$. The sequence of mineral deposition indicates the existence of four mineralizing stages and one supergene alteration: 1) Fe-(As); 2) Zn-Cu-Fe; 3) Pb-Sb-Cu-Ag; 4) Cu-Zn-Fe, and 5) carbonates, sulphates and supergene oxides.

In broad terms, it is possible to establish the following conclusions: a) there exist a mineralogical and textural variation with depth, the Pb-Sb-Cu-Ag stage reaching the maximum development; b) a temperature decrease during the formation of sph. I, linked to the progressive increase in Fe-content of the sphalerite has been detected; c) the compositional homogeneity of the bournonite (and the fair lack of As in the tetrahedrite) could indicate the existence of a possible tendency to individually crystallise the Sb and As sulphosalts, according to the trend Bi → Sb → As.

Key words: *Sulphides, Pb-Sb-Cu-Ag sulphosalts, Paragenesis, Sierra Almagrera.*

RESUMEN

La mineralización filoniana de Sierra Almagrera presenta una interesante paragénesis caracterizada por la presencia de sulfuros de metales base y sulfosales de Pb-Sb-Cu-Ag. Se ha identificado una secuencialidad textural y química de las distintas fases minerales, según la cual los sulfuros poseen variaciones significativas de las proporciones de Ag, Sb (galena), Fe (esfalerita), y Sb, Zn (calcopirita), y en la que las sulfosales son fundamentalmente sulfoantimoniuros (bournonita: $Cu_{0.98} Pb_{0.96} Sb_{0.98} S_{3.04}$, boulangerita $Pb_{4.8} Sb_{3.8} S_{11.34}$ y tetraedrita anómala $Ag_{0.6} Cu_{9.7} Zn_{3.6} Fe_{0.44} Sb_{3.47} S_{13}$). La secuencia de deposición mineral indica la existencia de cuatro etapas de mineralización y una de alteración supergénica: 1) Fe-(As); 2) Zn-Cu-Fe; 3) Pb-Sb-Cu-Ag; 4) Cu-Zn-Fe, y 5) carbonatos, sulfatos y óxidos supergénicos.

De acuerdo con los datos obtenidos, se ha establecido que: a) existe una variación mineralógica y textural con la profundidad, siendo la tercera etapa mineralizadora la que alcanza un mayor desarrollo; b) se observa un decrecimiento de la temperatura (probablemente sin variación de presión), durante la formación de la esfalerita de primera generación (sph.I), atendiendo al incremento progresivo de su contenido en hierro, y c) la homogeneidad composicional de la bournonita (junto con la ausencia de arsénico en la tetraedrita), podría indicar una tendencia de cristalización individualizada de las fases de Sb y As, de acuerdo con la tendencia normal: Bi → Sb → As.

Palabras clave: *Sulfuros, sulfosales de Pb-Sb-Cu-Ag, Paragenesis, Sierra Almagrera.*

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Introduction

The Sierra Almagrera (SA) veins are considered to be the first mine workings of the Iberian Peninsula, together with those of Herrerías (Almería) and Riotinto (Huelva). One of the main veins, which was discovered in 1838, caused a mining stampede until the year 1858, with up to 1700 pits being opened to extract the lead and silver. Later, in 1865, the extraction of iron began, with a total production of 370,000 t until the end of the 19th. century, when mining activity was abandoned.

In spite of the intense mining activity, the research carried out on this area has been limited (Arribas & Moro, 1981, López Aguayo & Arana, 1987), and does not discuss the veins in great detail. Martínez Frías *et al.* (1989) show that the veins of the SA were formed as a consequence of Miocene epithermal activity related to shoshonitic volcanism.

The objective of the research reported here is the identification and analysis of the mineral phases which comprise the veins and establish their paragenetic relationships and stages of mineralisation.

Geological and tectonic setting

The metamorphic massif of the SA is antiform with and NE-SW axis, situated in the Alpujárride Com-

plex of the Internal Zone of the Betic Cordillera of SE Spain (fig. 1). It is composed, to a large extent, of graphitic phyllites, quartz-rich phyllites and quartzites, with a paragenesis of quartz, muscovite, graphite and (seldom) biotite and garnet.

The present position of the SA is the result of a «detrochement» of an important megastructure, the Palomares fault (fig. 1). This fault caused the displacement of the metamorphic massifs of the SA and the Sierra Cabrera (Alvado, 1986) in the early sinistral, ductile phase. Martín Escorza & López Ruiz (1988) suggest a later brittle dextral phase for the Palomares fault, which controlled the spatial distribution of the volcanic rocks of SE Spain and, probably also, the hydrothermalism which gave rise to the formation of the veins of the SA (Martínez Frías *et al.*, 1989).

The Sierra Almagrera veins

Geology

The veins are located exclusively in the western part of the SA and trend N10W and N30-40W, with very variable dips (10-90°) (fig. 1), almost always towards the east. Presently, there only remains visible on the surface some small ore veins which vary between 10-30 cm (fig. 2A), although the «Jaroso» and

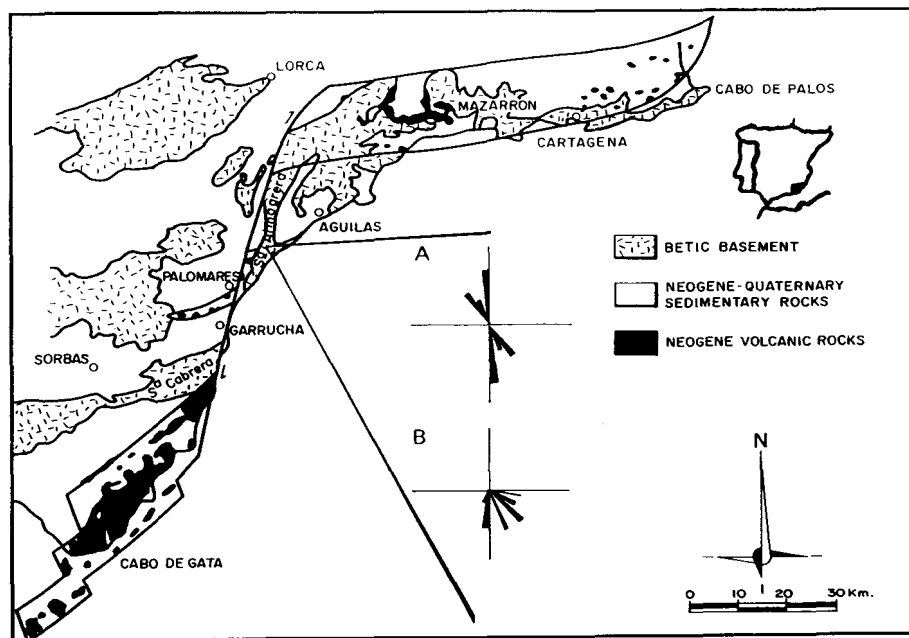


Fig. 1.—General scheme of the Sierra Almagrera (as part of the Betic Cordillera), in which its relationship to the Palomares fault and the volcanic rocks can be seen. A and B: Principal strikes and dips of the ore veins. Based on Martín Escorza & López Ruiz (1988) and Martínez Frías *et al.* (1989)

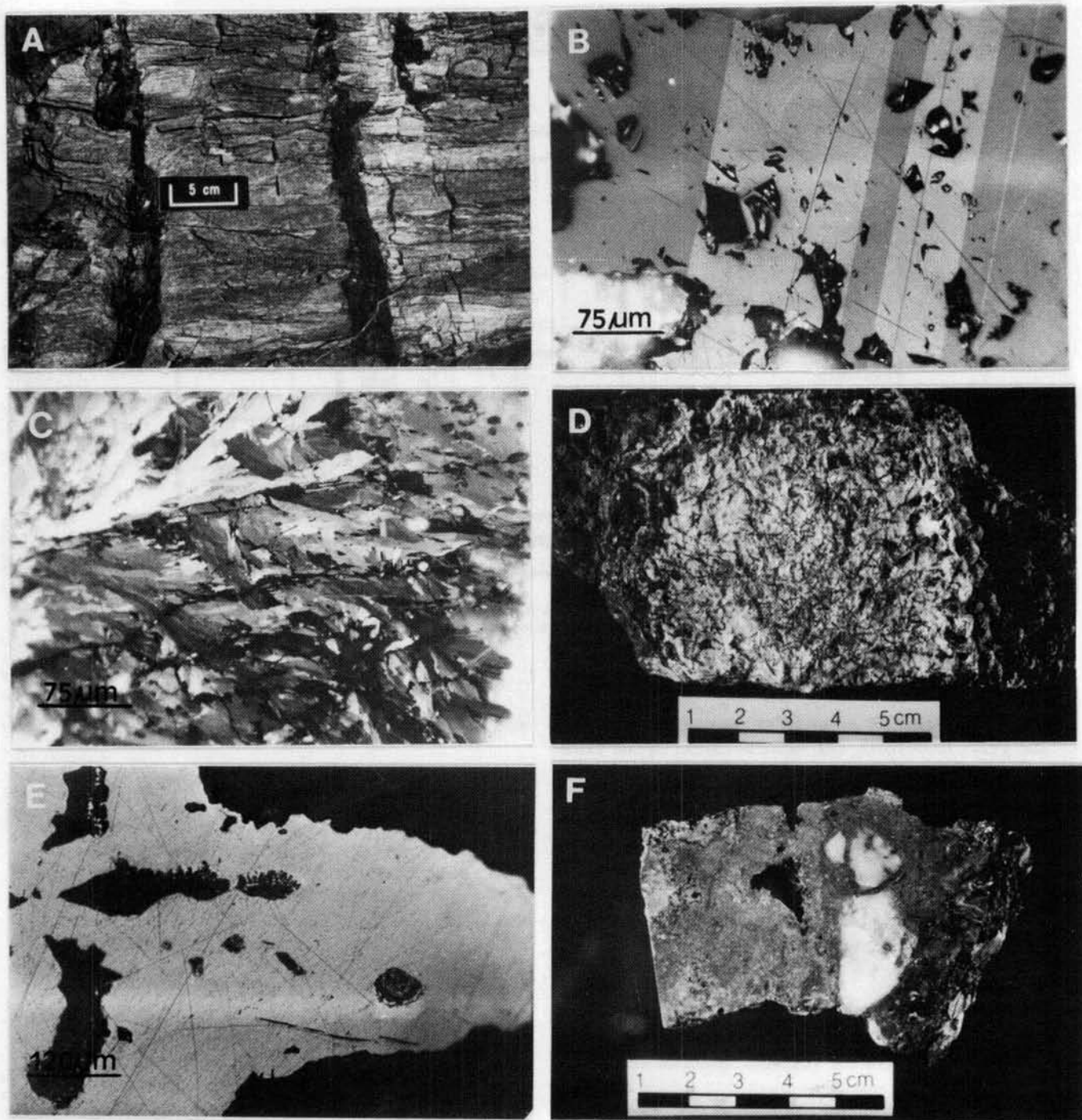


Fig. 2.—A) Small ore veins, Sierra Almagrera, composed of Fe oxides, barite, siderite and galena. Upper part of the vein system. B) Twinned bournonite grain. C) Radial-fibrous grains of boulangerite. D) Dendritic galena crystals included in amorphous milky barite. E) Inclusions of sphalerite and chalcopyrite in the branches of the dendritic galena. F) Well-cemented breccias, consisting of milky quartz, pyrite, fragments of the enclosing phyllites and some arsenopyrite.

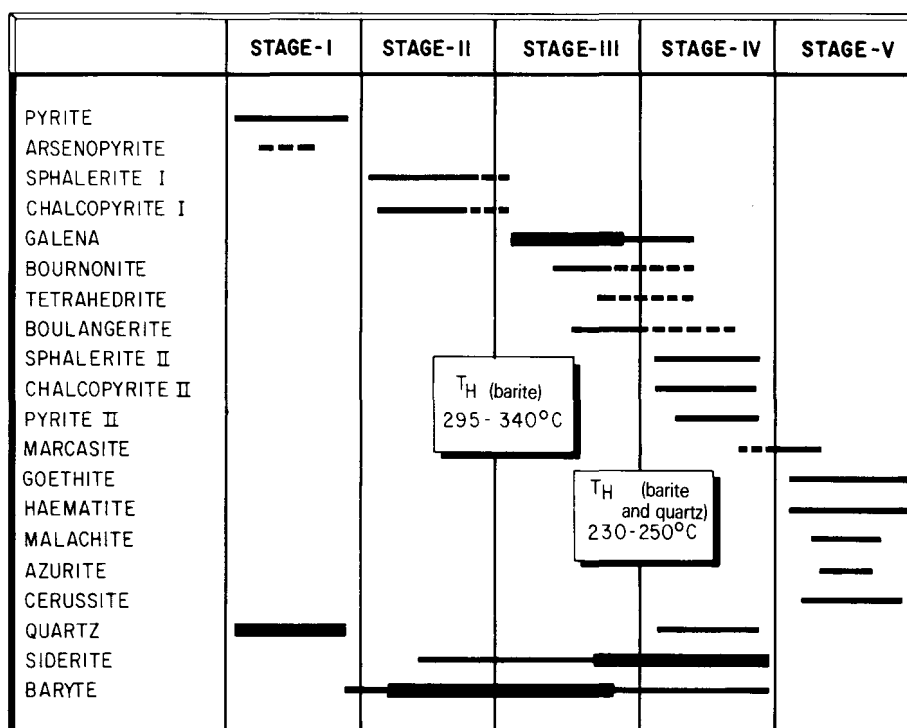


Fig. 3.—Mineralising stages and paragenetic sequence of the Sierra Almagrera veins. Stages I-IV: hypogenic mineralogical phases; Stage V: supergene minerals.

«Francés» veins of up to 10 m were worked during the years 1839-1880. The vertical extent of the veins exceeds 400 m in many cases. A vertical zonation has been identified as follows:

1. Alteration zone (0-50 m); supergene oxides, carbonates and sulphates of Fe, Cu, Pb and Zn.

2. Sulphosalt-sulphides zone (50-300 m); bournonite, boulangerite (figs. 2B & 2C), tetrahedrite, galena, sphalerite, chalcopryrite, pyrite, marcasite, barite, siderite and (rarely) quartz. Textures: crackle breccias, colomorph banding and dendritic intergrowths (fig. 2D).

3. Zone of sulphides-sulphosalts (300-350 m); principally sphalerite, chalcopryrite, bournonite, barite and siderite (rare). Textures: breccias and small fracture fillings.

4. Zone of sulphides (> 350 m): principally pyrite and minor arsenopyrite, barite (very scarce) and quartz. Textures: breccias and small fracture filling.

Hydrothermal alteration is generally weakly developed around the SA veins and rarely extends more than a few meters away the veins. The types of alteration observed in the wallrocks are silicification, sericitization and propylitization. No zoning has been observed.

Sulphide and sulphosalt mineralogy and paragenesis

The ore minerals of the SA veins are a simple intergrowth of base metal sulphides and Pb-Sb-Cu-Ag sulphosalts. In order of abundance they are galena, sphalerite, chalcopryrite, pyrite, bournonite, tetrahedrite, boulangerite and arsenopyrite. Sulphides and sulphosalts making up less than 10 % by volume of the veins. Gangue minerals include barite, siderite and quartz. Oxidized fractures contain goethite, haematite, malachite, azurite and cerussite.

Mineral deposition is divided into five paragenetic phases (fig. 3): 1) pyrite I and arsenopyrite; 2) chalcopryrite I and sphalerite I; 3) galena, bournonite, tetrahedrite, boulangerite; 4) sphalerite II, chalcopryrite II and pyrite II, and 5) supergene sulphides and oxides. The minerals corresponding to stages 2, 3 and 4 are deposited between 230-340°C (Martínez Frías *et al.*, 1989). These authors have identified two types of fluid inclusions: *a*) two-phase and three-phase aqueous-carbonic inclusions in which the bubble does not usually exceed 50 % of the total inclusion and whose homogenization temperatures vary between 295-340°C, and *b*) aqueous inclusions with temperature ranges between 230-250°C.

Galena

The galena appears forming part of the crackle breccias as idiomorphic crystals up to 3 cm and included in the masses of milky, amorphous barite, in the form of dendritic crystals (figs. 2D & 2E). Massive aggregates of galena have also been observed with small fracture-fillings of sulphosalts, principally tetrahedrite. Its composition conforms to the theoretical formula. Only the galena grains associated with sulphosalts show a certain enrichment in Ag and Sb and minor proportions of Hg, Zn and Cu (table 1).

Sphalerite

Sphalerite is present as inclusions in galena (sph. I) (fig. 2E) and in colomorphous bands (sph. II). The former corresponds to small irregular bodies (5-30 μm) intergrown with the chalcopyrite (cp. I). The banded sphalerite has a much clearer colour and the width of the bands does not exceed 5 cm.

The composition of both types is similar, with significant proportions of Fe (sph. I: 0.39-2.23 wt % and sph. II: 0.09-1.04 wt %). A progressive increase in the Fe content from the centre to the boundary of the grains has been observed in the sphalerite which appears as inclusions (sph. I) (table 1). The content of Cd can reach 0.73 wt % in type sph. I. Other elements, Mn, Sb, Tl, Ag, As and Hg appear in small quantities, never exceeding 0.6 wt %.

Chalcopyrite

In a similar manner, the chalcopyrite corresponding to the first phase of mineralisation (cp. I) appears intergrown with the sphalerite in the form of small inclusions (5-30 μm) (fig. 2E). Nevertheless, the presence of chalcopyrite is more frequent in the crackle breccia zones (cp. II), associated with galena and sulphosalts (bournonite and tetrahedrite). Generally, the crystals are idio-subidiomorphic ($\approx 300 \mu\text{m}$), although massive polycrystalline aggregates filling small cavities and fractures have been observed.

Both types of chalcopyrite possess quantities of Sb and Zn which are specially significant in the cp. II (Sb: 2.15 wt %, Zn: 1.22 wt %). The cp. II also has a small content of Ag (0.85 wt %), possibly owing to its association with the tetrahedrite.

Pyrite

Pyrite is the principal mineral found in the deep levels of the SA veins (py. I). It forms part of the well-

cemented breccias, consisting of milky quartz and fragments of the enclosing phyllites (fig. 2F). A porous, late pyrite (py. II) has been observed, filling spaces in the galena. In both cases, the crystal form massive, irregular aggregates with a very uniform composition (table 1).

Arsenopyrite

Arsenopyrite is very scarce mineral. The crystals are idiomorphic ($\approx 50 \mu\text{m}$), frequently with a complex, multiple twin. It is present in the form of disseminations and fracture-fillings in quartz, associated with py. I.

Bournonite

Bournonite appears in the superficial levels of the veins, associated with dendritic galena and in the crackle breccias related to cp. II, galena and tetrahedrite. It, usually, fills small voids and fractures, as twinned polycrystalline aggregates (fig. 2B). Its average composition is $\text{Cu}_{0.98} \text{Pb}_{0.96} \text{Sb}_{0.98} \text{S}_{3.04}$. Small quantities of Zn, Fe, Hg, Ag and Tl have been detected, but do not exceed 0.4 wt % (table 2).

Tetrahedrite

The identification of this sulphosalt is of a great interest because its composition is somewhat peculiar (table 2), posing difficulty as to its exact designation within the freibergite-argentotennantite series. It occurs as subidiomorphic crystals of around 300 μm and polycrystalline masses filling in small cracks in the gangue associated with bournonite, galena and cp. II. The mean composition is $\text{Ag}_{0.6} \text{Cu}_{9.7} \text{Zn}_{3.6} \text{Fe}_{0.44} \text{Sb}_{3.47} \text{S}_{13}$.

Boulangerite

This sulphosalt has been found in the upper levels of the veins as inclusions in amorphous milky barite. It always appears associated with galena in the form of radial, fibrous crystals (200 μm -1 cm) (fig. 2C). Its average composition is $\text{Pb}_{4.8} \text{Sb}_{3.8} \text{S}_{11.34}$. Small amounts of Cu, Hg, and Tl have been detected (table 2).

Mineralogical assemblages and chemical characteristics

Compositions of sulphides and sulphosalts (tables 1 and 2) were achieved by electron microprobe

Table 1.—Electron microprobe analyses of sulphides from samples selected to represent the four mineralising stages; b = boundary and c = center of the sphalerite grain. The results were obtained by using of a Camebax-MBX microprobe. Standards were natural and synthetic base-metal sulphides and sulphosalts (standard collection of the Mineralogisches-Petrographisches Institute, University of Heidelberg). ZAF correction were applied.

S	Cu	Fe	Zn	Ag	As	Cd	Pb	Hg	Mn	Sb	Tl	Total
Galena												
14.48	—	—	—	—	—	—	84.44	—	—	—	0.36	99.28
13.32	—	—	—	—	—	—	86.00	—	—	—	0.50	99.82
15.29	0.05	—	0.13	1.53	—	—	80.56	0.30	—	1.76	—	99.62
14.43	—	—	—	—	—	—	84.49	—	—	—	0.30	99.22
13.35	—	—	—	—	—	—	85.57	—	—	—	0.40	99.72
Sphalerite												
32.12	0.06	1.04	65.82	0.26	—	0.02	—	0.27	0.12	—	0.29	100.00 (II)
32.26	0.03	0.09	66.77	0.26	—	0.20	—	—	0.07	—	0.28	99.96 (II)
31.66	0.04	0.14	66.43	—	—	0.23	0.21	0.26	0.18	0.22	0.16	99.53 (II)
31.92c	—	0.39	65.60	0.40	—	0.73	—	—	0.20	0.46	0.20	99.90 (I)
32.29	0.19	1.31	65.47	—	0.04	0.27	—	—	0.18	0.40	0.30	100.45 (I)
32.44	0.37	1.33	65.09	—	—	0.04	—	—	0.22	0.51	0.25	100.25 (I)
32.36	0.15	1.39	65.00	—	—	0.73	—	—	0.17	—	0.28	100.08 (I)
32.29	0.16	2.07	64.94	0.26	—	0.03	—	—	0.05	0.50	0.26	100.56 (I)
32.54b	0.06	2.23	63.68	—	—	0.47	—	—	0.03	—	0.14	99.15 (I)
32.09	—	0.10	66.97	—	—	0.20	—	—	0.03	—	—	99.39 (II)
32.14	—	—	67.35	—	—	0.22	—	—	0.18	—	—	99.89 (II)
Chalcopyrite												
36.25	33.70	28.37	0.40	—	0.14	—	—	—	—	1.29	—	100.15 (II)
32.31	35.70	26.87	1.22	0.85	—	—	0.62	—	—	2.15	—	99.72 (II)
34.14	35.21	29.35	—	—	—	—	—	—	—	—	—	98.70 (II)
34.26	35.75	28.97	0.10	—	—	—	—	—	—	0.33	—	99.41 (I)
34.18	35.17	29.05	0.13	—	—	—	—	—	—	0.41	—	98.94 (I)
34.53	35.82	28.75	—	—	—	—	—	—	—	—	—	99.30 (I)
Pyrite												
52.55	0.02	46.51	0.01	—	—	—	—	—	—	—	0.03	99.12 (I)
52.87	—	46.60	—	—	—	—	0.05	—	—	—	0.02	99.54 (I)
52.50	—	46.29	—	—	—	—	0.03	—	—	—	—	98.82 (II)
52.41	—	46.35	—	—	—	—	—	—	—	—	0.03	98.79 (II)
52.87	—	46.28	—	—	—	—	—	—	—	—	0.04	99.19 (II)

Table 2.—Electron microprobe analyses of sulphosalts. Analytical conditions: see table 1.

S	Cu	Fe	Zn	Ag	As	Cd	Pb	Hg	Mn	Sb	Tl	Total
Bournonite												
19.95	12.19	—	—	—	—	—	40.67	—	—	25.99	0.09	98.89
19.72	12.53	—	—	—	—	—	41.33	—	—	25.93	—	99.51
20.14	12.11	—	—	—	—	—	41.80	—	—	25.01	0.24	99.30
19.62	13.46	0.25	—	—	—	—	40.73	—	—	24.67	—	98.73
19.95	12.42	—	—	0.21	—	—	41.68	—	—	24.76	—	99.02
19.72	12.53	—	—	—	—	—	41.33	—	—	25.93	—	99.51
19.69	13.54	0.08	—	—	—	—	40.72	—	—	24.84	—	98.87
19.37	13.74	0.12	0.14	—	—	—	39.01	—	—	25.73	—	98.11
19.18	13.74	0.27	0.16	—	—	—	40.56	—	—	25.41	—	99.32
21.08	14.92	0.06	—	—	—	—	40.35	0.36	—	23.31	—	100.08
Tetrahedrite												
23.18	35.93	0.83	14.48	2.69	—	—	—	—	—	23.08	—	100.19
24.21	33.57	2.38	11.45	4.89	—	—	—	—	—	23.38	—	99.88
23.28	34.58	1.75	12.56	3.42	—	—	—	—	—	24.43	—	100.02
23.65	34.42	1.59	13.70	3.39	—	—	—	—	—	24.38	—	101.13
23.86	34.32	0.87	13.68	3.67	—	—	—	—	—	24.42	—	100.82
22.65	35.80	1.02	14.06	3.68	—	—	—	—	—	23.26	—	100.47
Boulangerite												
20.54	0.05	—	—	—	—	—	52.41	0.27	—	25.73	—	99.00
20.22	—	—	—	—	—	—	53.34	—	—	26.67	0.25	100.48
19.11	0.04	—	—	—	—	—	56.40	—	—	23.74	—	99.29
19.02	—	—	—	—	—	—	54.24	—	—	25.46	—	98.72
19.93	0.07	—	—	—	—	—	53.60	—	—	25.49	0.23	99.32

analysis (Camebax-MBX). The standards used were natural and synthetic base-metal sulphides and sulphosalts (standard collection of the Mineralogisches-Petrographisches Institute, University of Heidelberg). ZAF corrections were applied.

Sphalerite-chalcopyrite-pyrite

In accordance with the temperature ranges obtained from fluid inclusions (230-250 °C and 295-340 °C) (Martínez Frías *et al.*, 1989) and taking into account the composition of the sphalerite, the molar ratios observed (ZnS: 96.18-100 Mol %, CuS: 0-0.56 Mol % and FeS: 0-3.73 Mol %) are coherent with the compositional field cp + py + sph at 300° C, within the central portion of the system Cu-Fe-Zn-S (Kojima & Sugaki, 1985). This association agrees with the paragenesis of the SA veins. Likewise, the average composition of the chalcopyrite $Ag_{0.01} Sb_{0.02} Zn_{0.03} Cu_{1.03} Fe_{0.92} S_{1.98}$ appears to mark the boundary, in this same system, between the compositional field cp + py + sph and bn + cp + py + sph. This could indicate that at lower temperatures (Th in barites coexistent with chalcopyrite = 230-250° C), the line which represents the sulphur-deficient assemblage between both compositional fields (Kojima & Sugaki, 1985) could be displaced along the plane FeS-CuS towards areas richer in copper.

With respect to the pyrite, neither copper nor zinc was detected, in significant amounts in any of the grains that were analysed.

On the other hand, the progressive increase in Fe content in the sphalerite inclusions (0.39 wt %-2.23 wt % from the centre to the boundary) (table 1) could be related to the observations of Hutchinson & Scott (1981) about the Zn/Fe ratio in sphalerites. These authors found that the most obvious effect of increasing temperature at constant pressure is the steady increase in the Zn content of intermediate solid solution, with a concomitant decrease in Fe. The Zn/Fe ratio of the intermediate solid solution increase from approximately zero at low temperatures to 0.28 at 723° C and 1 bar. As such, the decrease in the ratio Zn/Fe of the SA sphalerites could be conditioned by a progressive cooling, without pressure variation, during the formation of the sph. I.

Bournonite-boulangerite

The bournonite shows a homogeneous composition, with minor quantities of Zn, Fe, Hg, Ag and Tl. It is important to point out the absence of As in all the grains analysed (table 2), as isomorphic substitution between bournonite and seligmannite

(CuPbAsS₃) frequently occurs in nature. This could indicate the existence of a chemical splitting, during the Sb-As sulphosalts crystallization, in relation with the trend Bi → Sb → As (Kostov & Stefanova, 1981), in accordance with the decrease of temperature.

On the other hand, phase relations in the pseudoternary system Cu₂S-PbS-Sb₂S₃ (Hoda & Chang, 1975), at 300 °C, reveal the existence of a restricted solid solution between bournonite and meneghinite (CuPb₁₃Sb₇S₂₄). The stability field of meneghinite in this system is reduced when the temperature is lowered. For this reason, and taking into account the depositional temperatures of the zone richest in sulphosalts in the SA veins (230-250 °C), a certain relationship can be established between the absence of meneghinite (as an intermediate between bournonite and boulangerite) and the temperatures observed. Thus, the decrease in temperature would be associated with an impoverishment in Cu and an increase in Pb and Sb from the formation of bournonite to that of boulangerite (later).

The composition of the boulangerite is fairly uniform with minor quantities of Cu, Hg and Tl, which do not exceed 0.3 wt % (table 2). Salanci (1979) demonstrated experimentally that the boulangerite persists as a stable facies to 270 °C. This corresponds with its late appearance in the SA veins.

Tetrahedrite

In relation with the anomalous composition of the silver tetrahedrite, from the SA veins (table 1), is important to point out that freibergite and argentotennantite are the established names for Ag-rich members of the tetrahedrite-tennantite series, but their compositional limits are not clearly defined. Riley (1974) proposed the name freibergite for compositions with more than 1/3 Cu. Peterson & Miller (1986) suggested that the freibergite should be defined as a member of the tetrahedrite group with Sb > As and the trigonal-12(e) site predominantly occupied by Ag. Kostov & Stefanova (1981) propose an ideal formula for freibergite $Cu_4 Ag_6 (Fe, Zn)_2 Sb_4 S_{13}$.

In broad terms, the tetrahedrite chemistry approximates the following stoichiometry (Sack & Loucks, 1985) $TRG(Cu, Ag)_6 TET[Cu_{2/3}(Fe, Zn, Cd, Hg, Pb)_{1/3}]_6 SM(Sb, As, Bi)_4 OCT(S, Se)_{13}$ (TGR, TET, SM and OCT stand for trigonal planar, tetrahedral, semimetal, and octahedral sites, respectively). The semimetals are typically divided among three tetrahedral sites and one trigonal planar site (Johnson *et al.*, 1988). Considerable departures from the ideal formula are widely reported in the literature, particularly in the

case of Ag-bearing tetrahedrite (Johnson *et al.*, 1988). In this sense, the silver-tetrahedrite from the SA veins is deficient in silver ($\bar{x} = \text{Ag}_{0.6}$), antimony ($\bar{x} = \text{Sb}_{3.47}$) and sulphur ($\bar{x}_{\text{(experimental)}} = \text{S}_{12.24}$), and contains an excess in zinc ($\bar{x} = \text{Zn}_{3.6}$) and copper ($\text{Cu}_{9.7}$), in relation with the theoretical formula of freibergite. It is known that the incorporation of divalent cations into sulphur-deficient tetrahedrites and tennantites stabilizes the lattices by filling up vacancies to the stoichiometric limit of $\text{Cu}_{10} \text{Me}_2 \text{Sb}_4 \text{S}_{13}$ (Me = Fe, Zn), the bivalent copper atoms being entirely reduced to a monovalent state. Silver and mercury are among the more frequent cations in such admixtures (Sugaki *et al.*, 1976). However, our analyses reveal no sufficient sulphur deficiency which can explain the chemical variations of the SA silver tetrahedrite. So, the significant excess in zinc and copper could be also related, in our case, to the deficiency in silver and antimony. It is important to point out that recrystallised tetrahedrites from Silvermines (Ireland) (Zakrzewski, 1989) are characterised by a low content of silver ($\text{Ag}_{0.35}$), which is similar to that of the SA silver-tetrahedrite.

Conclusions

The Sierra Almagrera veins are composed of base metal sulphides and sulphosalts of Pb-Sb-Cu-Ag. The sequence of mineral deposition indicates the existence of four stages of mineralisation and one of supergene alteration: 1) Fe-(±As); 2) Zn-Cu-Fe; 3) Pb-Sb-Cu-Ag; 4) Cu-Zn-Fe and 5) carbonates, sulphates and supergene oxides. Considering the thermometric results obtained by Martínez Frías *et al.* (1989) and the detailed analysis of the mineral assemblages and the chemical characteristics of the sulphides and sulphosalts, it is possible to establish the following conclusions: a) there exists a mineralogical and textural variation with depth, the Pb-Sb-Cu-Ag stage reaching the maximum development; b) the composition of sphalerite and chalcopyrite agrees broadly with the experimental results of Kojima & Sugaki (1985) at 300 °C in the Cu-Fe-Zn-S system; c) a temperature decrease during the formation of sph. I, linked to the progressive increase in Fe-content of the sphalerite has been detected; d) the compositional homogeneity of the bournonite (and the fair lack of As in the tetrahedrite) could indicate the existence, in the SA veins, of a possible tendency to individually crystallise the Sb and As sulphosalts, according to the trend $\text{Bi} \rightarrow \text{Sb} \rightarrow \text{As}$ (Kostov & Stefanova, 1981); e) in the pseudoternary system $\text{Cu}_2\text{S-PbS-Sb}_2\text{S}_3$, the transition from bournonite to boulangerite takes place, in the SA veins (230-250 °C), without the appearance of intermediate phases (meneghinite), and

f) importance is given to the possible substitution of sulphur, antimony and silver by zinc and copper, in the silver-tetrahedrite lattice, probably conditioned by recrystallization processes.

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