Silver and lead mineralogy in gossan-type deposits of Sierra de Cartagena, southeast Spain

J. A. López García, R. Lunar and R. Oyarzun

The strata-bound Pb–Zn–Ag deposits of Sierra de Cartagena, Murcia province, southeast Spain (Fig. 1), have been intermittently exploited since Roman times—first for silver, and, in modern times, for lead, zinc and silver. These deposits are currently being worked in open-pit operations by the Sociedad Minera y Metalúrgica Pecharroya-España. Production in 1986 was 34,989 t Pb concentrate, 58,078 t Zn concentrate and 25,000 kg Ag.

Silver mineralization in gossan-type deposits has presented a major mineralogical and metallurgical problem since Roman times. The Romans were probably the best prospectors and metallurgists of classical times and knew how to exploit Ag-bearing jarosite-type minerals in the gossans of the Iberian Pyrite Belt; furthermore, they may have used jarosite-type minerals as a guide to the richest Ag horizons in the ore deposits. Indeed, they searched for the lower contact of the gossans (as shown by the most important Roman workings), where silver becomes concentrated in the form of Ag-jarosite and other oxide minerals.

Today, classical—some may even say old-fashioned—studies of gossan mineralogy and textures are of major relevance to the extraction of precious metals from these and similar oxide ore deposits in that a knowledge of the ore mineralogy is essential in planning a heap-leach operation. Heap leaching is now used to treat Au–Ag bearing gossans at Tharsis, Huelva province, Spain (reserves exceed 5,000,000 t of tailings and in-situ gossan ore grading 1.8 g/t Au and 37.6 g/t Ag1), and at Grantsville, Nevada, U.S.A., where the open-pit operation has reserves of 800,000 t of gossan ore grading 4.3 oz/t silver.

The Sierra de Cartagena orebodies exhibit distinct gossan-type oxidation zones, which are locally enriched in lead and/or silver relative to the primary ores. Ore grades and the Pb- and Ag-bearing minerals in the oxide zones at San Valentin and El Estrecho (Fig. 1) were studied as part of a preliminary evaluation of the supergene orebodies, which constitute reserves of 15,000,000 t. Since magnetic separation has been considered as a commercial method for the preconcentration of silver minerals from oxide ore, the method was used in the present study to effect separations from a 0.10- to 0.12-mm size fraction. Three different magnetic fractions were obtained: non-magnetic (0.5 A); intermediate (0.5–0.3 A); and magnetic (0.3 A). The test samples obtained in this way were chemically analysed by atomic absorption spectrophotometry to determine the distribution of Pb and Ag between the different fractions.

Geology

The ore deposits of Sierra de Cartagena have been studied by several authors.4-9 Geologically, the deposits are located in the internal zone (Betic Zone) of the Betic Cordilleras, this

Asian mining '88

Papers presented at the 'Asian mining '88' conference, organized by the Institution of Mining and Metallurgy and held in Kuala Lumpur, Malaysia, from 8 to 10 March, 1988

Contents include reviews of the minerals industry in Malaysia and the effects of the 'tin crisis' on its production of tin; and papers on the role of the United Nations and other bodies in exploration programmes for mineral deposits, on slope stability problems in tropical areas and on mineral processing operations.

Limp, 296 mm x 208 mm, 240 pages
Price £4.00 ISBN 1 870760 00 5
Published in March, 1988, by the Institution of Mining and Metallurgy

Orders, with remittance, should be sent to the IMM, 44 Portland Place, London W1N 4BR, England
The ore deposits of the area are of the massive strata-bound type, the local term for which is 'mantos'. Two generations of mantos are recognized in the area. The first (Manto I) is located within the base of a carbonate rock sequence of the Lower unit and is spatially related to dolerite bodies that belong to the same unit. The second (Manto II) was emplaced in the Upper Nevado-Filabride unit and is also spatially related to basic rocks (Fig. 2). The mantos underwent strong supergene alteration, which resulted in the formation of significant oxide zones.

**Mineralogy**

**Primary ores**

Two types of mineralogical association are observed in the mantos: 
- Manto I:
  - Green and purple phyllites
  - Black dolomites
  - Limestones
  - Marls
  - Basalts, andesites and rhyodacites

- Manto II:
  - Greenstones
  - Light grey schists
  - Flaggy limestones
  - Dolerites
  - Marbles
  - Green and purple phyllites
  - Quartzites
  - Red gypsum-bearing phyllites
  - Marls
  - Black dolomites
  - Limestones

The mineralogy of Manto I comprises pyrite, marcasite, tetrahedrite, and stannite disseminated in a matrix of siderite with variable amounts of substitution by Zn and Mn. Grades in the mineralization are 1 wt% Pb, 1.5 wt% Zn and 15 g/t Ag.

The mineralogy of Manto II contains pyrite, marcasite, and sphalerite as the principal minerals. Minor amounts of chalcopyrite, tetrahedrite, and stannite are also present. In both mantos, the carbonate is siderite with varying degrees of substitution by Zn and Mn.

**Gossans**

The gossans of Sierra de Cartagena are the result of the supergene alteration of primary assemblages to form two distinct oxide horizons.
Table 1 San Valentin gossan ore, horizon 1.—Pb and Ag grades of core samples and associated magnetic fractions

<table>
<thead>
<tr>
<th>Fraction</th>
<th>Total sample</th>
<th>Non-magnetic fraction</th>
<th>Intermediate fraction</th>
<th>Magnetic fraction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pb, wt%</td>
<td>Ag, g/t</td>
<td>Pb, wt%</td>
<td>Ag, g/t</td>
</tr>
<tr>
<td>DDH 923</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10.0-12.5 m</td>
<td>4.70</td>
<td>30</td>
<td>7.35</td>
<td>25</td>
</tr>
<tr>
<td>12.5-15.0 m</td>
<td>1.85</td>
<td>30</td>
<td>1.94</td>
<td>30</td>
</tr>
<tr>
<td>15.0-17.5 m</td>
<td>1.60</td>
<td>44</td>
<td>1.05</td>
<td>58</td>
</tr>
<tr>
<td>17.5-19.3 m</td>
<td>2.15</td>
<td>68</td>
<td>0.90</td>
<td>145</td>
</tr>
<tr>
<td>19.3-21.8 m</td>
<td>1.57</td>
<td>62</td>
<td>1.02</td>
<td>85</td>
</tr>
<tr>
<td>21.8-22.8 m</td>
<td>1.32</td>
<td>45</td>
<td>0.75</td>
<td>185</td>
</tr>
<tr>
<td>DDH 931</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.0-7.75 m</td>
<td>2.17</td>
<td>15</td>
<td>6.60</td>
<td>30</td>
</tr>
<tr>
<td>7.75-10.2 m</td>
<td>1.24</td>
<td>80</td>
<td>0.35</td>
<td>36</td>
</tr>
<tr>
<td>10.2-13.1 m</td>
<td>0.55</td>
<td>39</td>
<td>0.70</td>
<td>38</td>
</tr>
</tbody>
</table>

Table 2 San Valentin gossan, horizon (1)—main ore minerals in magnetic fractions (cores as Table 1)

<table>
<thead>
<tr>
<th>Fraction</th>
<th>Pb DDH 923</th>
<th>DDH 931</th>
<th>Ag DDH 923 and DDH 931</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-magnetic</td>
<td>Anglesite (−)</td>
<td>Cerussite, anglesite (−)</td>
<td>Cerargyrite (⁺), native silver (−)</td>
</tr>
<tr>
<td>Intermediate</td>
<td>Anglesite Pb-coronadite (+)</td>
<td>Pb-coronadite Pb-coronadite</td>
<td>Cerargyrite (−), native silver (−)</td>
</tr>
<tr>
<td>Magnetic</td>
<td>Pb-coronadite (−)</td>
<td>Pb-coronadite</td>
<td>Cerargyrite (−), native silver (−)</td>
</tr>
</tbody>
</table>

Proportion in fraction: +, major; ±, moderate; -, minor.

Table 3 El Estrecho gossan ore, horizon (2)—Pb and Ag grades of samples and associated magnetic fractions

<table>
<thead>
<tr>
<th>Fraction</th>
<th>Pb</th>
<th>Ag</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-magnetic</td>
<td>Anglesite (−)</td>
<td>Native silver (−)</td>
</tr>
<tr>
<td>Intermediate</td>
<td>Pb-coronadite (±), Pb-jarosite (−)</td>
<td>Native silver (±), jarosite (−)</td>
</tr>
<tr>
<td>Magnetic</td>
<td>Pb-coronadite (±), Pb-jarosite (±)</td>
<td>Native silver (±), jarosite (−)</td>
</tr>
</tbody>
</table>

Proportion in fraction: +, major; ±, moderate; -, minor.

metals present in the gossans are lead and silver. These were leached from the ores and precipitated as carbonates (Pb- and Ag-bearing jarosites, and anglesite), carbonates (cerussite), oxides (Pb-bearing coronadite and Pb-bearing jarosite), native silver and halides (cerargyrite). A simplified description of the processes responsible for the formation of these minerals in the gossans is presented as Fig. 3. Ore grades and element maps are displayed in Tables 1-4, and some textural features of the ores are shown in Figs. 4 and 5.
features have largely been obliterated (Fig. 5).

The preservation or loss of primary textures, as well as metal leaching, was related to the availability of iron sulphide minerals and the presence of carbonates, which controlled the acidity/alkalinity of the system. An example of this interdependence is the oxide zones derived from assemblage (2) (sulphide-carbonates-silica), where metal leaching was stronger and primary textures are infrequently observed. In assemblage (1) most of the iron is in the form of magnetic and siderite, whereas in assemblage (2) 28% of the iron forms pyrite and marcasite. The presence of these iron sulphides produced lower pH conditions (∼3, as indicated by the local occurrence of jarosite), resulting in a greater development of iron and manganese oxides. The important presence of Mn oxides in the oxide horizon developed from assemblage (2) is also a consequence of the high primary content of this element in the manto carbonates, which can contain as much as 15 wt% Mn.

The presence of a silver halide, such as cerargyrite, has a particular palaeo-environmental significance in that: this mineral forms only under arid or semi-arid conditions1—4—a climatic condition that is also indicated by the presence of smithsonite (a mineral of minor importance in the gossans of Cartagena). A contributing factor to the formation of cerargyrite was the proximity of this area to the sea, which resulted in an important wind-borne supply of chlorine.

Conclusions
Two strata-bound Pb-Zn-Ag orebodies (mantos) are currently being worked by the Sociedad Minera y Metalúrgica Peñarroya-España in the Sierra de Cartagena, southeast Spain. Associated with the primary ores are gossan-type oxidation zones; these supergene ores, which comprise two distinct mineral associations that were formed from the two primary manto assemblages under different pH conditions, are locally enriched in lead and/or silver.

A preliminary evaluation of the gossan ores at two of the open-pit mines was undertaken to investigate the distribution of Pb and Ag in the different magnetic fractions of the ore. The results indicate that magnetic separation as a first-stage preconcentration method after crushing could be used successfully prior to beneficiation of silver by heap leaching.

One of the factors that affect the profitability of heap leaching is the mineralogy of the ore1 4 significantly, a proportion of the silver ore mineralization (silver) at the gossans studied is amenable to heap leaching (neither mineral is a cyanide1). The dryish, Mediterranean climatic is ideal for heap leaching: minimum and maximum average temperatures (January and August, respectively) are 5.4°C and 31°C (annual rainfall, 287 mm). Hydrometallurgical tests should indicate the level of Ag extraction that can be achieved and the optimum reagent composition and consumption rate, as well as other factors, such as crushing size,
Fig. 4 Supergene horizon (1)—reflected-light photomicrographs of minerals and textures. (A) Roseate siderite (Sd); (B) roseate siderite (Sd) showing different stages of alteration to goethite (gt); (C) goethite (gt) replica texture after galena; (D) crystals of anglesite (AgI) intergrown with goethite (gt); (E) intergrowth of magnetite (Mt) and siderite (Sd); (F) hematite crystals (Hm) with goethite (gt) pseudomorphs after siderite; (G) hematite (Hm) and goethite (gt) preserving original banding of magnetite–siderite; (H) cerargyrite (Qg) crystals with inclusions of native silver (Ag) and intergrown with goethite (Gt).
Fig. 5 Supergene horizon (2)—reflected-light photomicrographs of minerals and textures. (A) Banded hematite \((Hm)\) and goethite \((Gr)\) after marcasite; \((B)\) banded texture of marcasite \((Mc)\) and carbonates \((Chto)\); \((C)\) goethite \((Gr)\) replica textures after sphalerite; \((D)\) goethite \((Gr)\) pseudomorphs after siderite; \((Hm)\) hematite; \((E)\) coronadite \((Co)\) and goethite \((Gr)\) pseudomorphs after marcasite; \((F)\) colloidal textures of coronadite \((Co)\) and goethite \((Gr)\); \((G)\) jarosite \((Jr)\) infilling voids in goethite \((Gr)\); \((H)\) colloidal textures of goethite \((Gr)\) and disseminated native silver \((Ag)\)
amount of solution needed to saturate the ore, etc. Before any major investment, however, careful consideration will have to be given to the rather low grades of silver (≤80 g t⁻¹ in bulk samples and 185 g t⁻¹ in magnetically separated ore) and to the depressed market price of the metal.

**References**


---

**New evidence of epithermal gold potential in andesitic volcanics of the Central Inlier, Jamaica**


Detrital native gold of high fineness is reported in drainage samples from the Mountain River at Cudjoe Hill on the southeast margin of the Central Inlier, St. Catherine Parish, Jamaica (Fig. 1). The gold is associated with volcanosedimentary sequences of andesitic affinities and with anomalous geochemical haloes for As and Ag, which are indicative of epithermal gold mineralization. The volcanic pipe has been locally intruded by Cretaceous granite at Ginger Ridge, 2.5 km southwest of Juan de Bolas Mountain (Fig. 1). The Caribbean plate is a favourable area for gold exploration, and by analogy with the main western Pacific plate margin, has potential for epithermal deposits related to volcanic hot springs at crustal plate boundaries. Jamaica has no record of gold mining, though Sawkins recognized the gold potential of mineralization in the Stanford Hill, Charing Cross and Gr. J. Mine localities in northeast Clarendon to the west of the present study area, which he classified as gold ore.

**Geochemistry**

Gold was observed in pan concentrates where the Mountain River emerging from a gorge in the Troyn Clauden Formation (site 10), Fig. 1. Field examination of andesitic volcanics of the Central Inlier (site 2), Fig. 1 indicated the presence of finely disseminated pyrite in the Arthur’s Seam Formation and Eastern Volcanic Group, which may therefore, be a primary source of gold.

Thirteen pan concentrate samples were analyzed by X-ray fluorescence (XRF) for 28 elements, including the gold pathfinder elements Au and Ag, which indicated the presence of a geochemical halo. The highest arsenic values coincide with the presence of chalcopyrite in bedrock. 50 ppm As at site (2), Fig. 1), and the higher silver values tend to reflect sites favourable for the accumulation of detrital gold, such as the Mountain River gorge (5-11 ppm Au), drainage samples from locations underlain by the Clun Hill Member of the Yellow Limestone Group (9 ppm Ag) and the alluvium near Lloyds (11 ppm Ag). (Fig 1). The ranges for other indicator elements are, ppm: Ba 45-1034; Zn 217-535; Sb 0-6; Co 53-231; and Mo 4-9. The higher values are anomalous and are indicative of epithermal mineralization.

**Geology**

The geology setting for gold in the Mountain River catchment basin is dominated by andesitic volcanics of the Arthur’s Seam Formation and Eastern Volcanic Group. They represent the oldest of the main Cretaceous subdivisions of the Central Inlier (Fig 1). The Arthur’s Seam Formation consists of poorly bedded, unsorted epiclastic volcanic conglomerates and breccias, together with subordinate laminated volcanic grits, sand-