Occurrence of gold (electrum) in the Lousal mine, Iberian pyrite belt, Portugal

Daniel P. S. de Oliveira, Carlos J. P. Rosa, Fernanda M. G. Guimarães, João X. Matos, Zélia Pereira, Vasco C. S. Frias
Laboratório Nacional de Energia e Geologia (LNEG), Portugal

Diogo R. N. Rosa
Geological Survey of Denmark and Greenland (GEUS)

J. M. Castelo Branco
AGC- Minas de Portugal, unipessoal (Lundin Mining Corporation)

Abstract. Recent exploration drill holes in the Lousal Mine, located within the Portuguese sector of the Iberian Pyrite Belt (IPB) yielded previously unknown and significant concentrations in gold (electrum) in a section of core consisting of hydrothermally altered banded sediments with massive pyrite and cobaltite. Research indicates that the gold (electrum) is present in veinlets within the more dominant massive pyrite and cobaltite associated with native bismuth and bismuthinite and is clearly late in the paragenetic sequence occurring also with fine chalcopyrite (± covellite). The gold (electrum) grains are small, seldom reaching more than 6 μm in length and half of that in thickness. EPMA results indicate that silver concentrations in the gold grains can be as high as 26 wt%.
These results show similarities with conclusions drawn from the IPB on the Spanish side where gold is found as electrum associated with abundant to common Co and Bi minerals. The gold is associated with pyrite, cobaltite and/or chalcopyrite and hosted by sedimentary facies. This gold is interpreted to have formed at high temperature (>300 °C) during the initial phases of massive sulfide formation. At Lousal the gold seems to occur related with hydrothermal alteration of the sulfides, and remobilized in late-stage shear zones.

Keywords: Lousal, Iberian Pyrite Belt, gold, electrum

1 Introduction

The Iberian Pyrite Belt (IPB) is a well-known Volcanic Hosted Massive Sulfide (VHMS) deposit province containing several world-class deposits. IPB deposits often contain subordinate gold values disseminated in sulfide ores and also occur locally in shear zones and even some of the high-tech metals such as Ge (Reiser et al. 2011) and In (de Oliveira et al, 2011).

The Lousal mine, is located in the Lousal-Caveira IPB NW sector (Fig. 1), an area limited by the Sado Tertiary Basin sediments to the N, E and S (Matos and Oliveira 2003; Oliveira et al. 2005).

Pyrite ore concentrates were produced at Lousal between 1900 and 1988. Presently the mine is in rehabilitation to acid mine drainage control (Silva et al. 2009). The Lousal massive sulfide deposit is located ~65 km NW of Neves Corvo.

The IPB comprises the Volcanic Sedimentary Complex (VSC) and the older Phyllite-Quartzite Group (PQ). The IPB is covered by the Baixo Alentejo Flysch sediments.

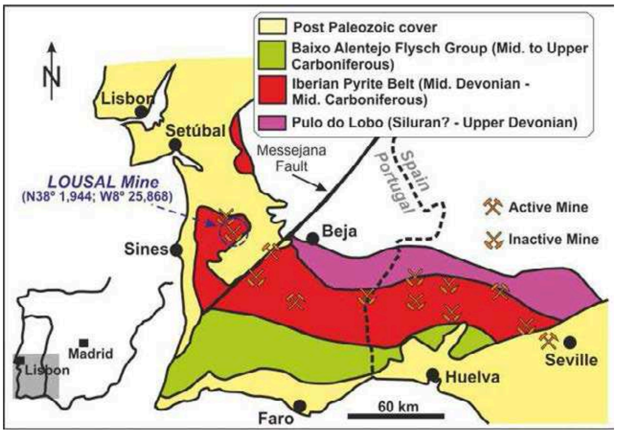

Figure 1. Location of the Lousal Mine within the geological setting of the Iberian Pyrite Belt.

At Lousal a VSC sequence is orientated N40W and compartmentalized by late Variscan N-S trending faults; the eastern sector is dominated by PQ rocks (Strauss 1970; Schermerhorn et al. 1987; Matos and Oliveira 2003; Matos and Relvas 2006). The Lousal structure consists of a narrow anticline with a nucleus formed by PQ lower Givetian age sediments and VSC units are present in both anticline limbs. PQ sediments overthrust the VSC in a SW direction (Rosa et al., 2010; Matos et al. in prep). In Lousal four separate volcanic centres could be outlined which are defined by coarse-grained porphyritic quartz-feldspar rocks with associated autoclastic breccias (Rosa et al., 2010), and due to the Variscan folding and faulting can reach thicknesses of 850 m or more (Strauss and Madel, 1974).

The Lousal VHMS deposit comprises 9 ore lenses that are lined up along one horizon extending for 1.5 km along strike (Strauss and Madel, 1974). The ore-bearing facies are predominantly fine-grained volcaniclastic units, black shales and felsic volcanic rocks. Black shales are of late Strunian age (Pereira, 2012).

This study complements a preliminary insight into the occurrence of electrum in the Lousal mine (De Oliveira et al., 2011) from samples obtained from two drill holes done in 2008 by AGC/Lundin Mining.

2 Ore geochemistry

Whole rock analytical results of selected samples in borehole LS08/01 indicate elevated concentrations of not only gold but also other elements (see Table 1, 700 m – 733,5 m borehole samples), namely copper, lead, zinc, bismuth, cobalt (and arsenic – not shown). Maximum values of ~67 g/t Au (which far exceeds those reported previously in the IPB, e.g. (Strauss and Beck, 1990) and 11 g/t Bi were obtained in one sample from drill hole LS08/01.

3 Gold in Lousal

Interesting gold values were detected throughout exploration drill holes (LS08/01 and LS08/02). However, significant concentrations were detected at approximately 700 m depth and although both holes show considerable amounts of gold, LS08/01 has considerably higher gold values (Table 1). Both holes intersected hydrothermally altered zones containing chlorite, silica and sulfide veins that locally occur as semi-massive sulfide mineralization, up to 0.5 m thick, with chalcopyrite and sphalerite as accessory minerals. The hydrothermal alteration and sulfide veins are hosted by dark grey shales and thin beds of quartzites of the PQ (late Strunian and lower Givetian age, respectively; Matos et al, 2011; Pereira et al., 2012), and by VSC dark grey shales of late Strunian age (Matos et al, 2011) and VSC (359±2 M.a. to 369±3.5 M.a.; Matos et al, *in prep.*). The hydrothermal altered intervals are delimited by thrust faults that disrupt the stratigraphy. Gold has been found to occur mostly in the hydrothermal altered zones associated with massive pyrite (close to a quartz-rich shear zone) that is replacing banded black shales, and also in the thrust zones. In hand specimen the pyrite appears as deformed rounded to subrounded grains and coalesces in places into more massive sections (Fig. 2).

Table 1. Partial results of whole rock geochemistry for selected samples from drill holes LS08/01and LS08/02. All values in ppm; number in brackets refers to the sample collection depth; Results in ppm.

	Au	Bi	Co	Cu	Pb	Sn	Zn
LOU 08/01-2(660,9)	40	79,5	628	11300	43	38	45
LOU 08/01-6(719,5)	2200	143	502	6980	147	12	841
LOU 08/01-7(732,4)	66700	11400	48400	9380	1850	44	41
LOU 08/01-8(733,5)	29400	7750	26000	3350	1230	23	189
LOU 08/01-11(835)	207	49,3	46	377	3740	122	11500
LOU 08/01-13(841,5)	14	8,5	62	285	7930	84	9030
LOU 08/01-14(720,6)	3140	469	866	4980	99	12	141
LOU 08/02(530.0)	1010	121	2860	3730	89	21	37
LOU 08/02(530.3)	578	24,3	1540	33200	88	90	75
LOU 08/02(623.6)	102	128	529	13200	202	43	4060
LOU 08/02(624.0)	143	239	795	13500	745	82	957
LOU 08/02(629.0)	30	101	554	21200	191	40	526
LOU 08/02(652.0)	179	114	1000	12000	299	8	655
LOU 08/02(669.8)	205	197	738	24500	168	54	259
LOU 08/02(670.0)	301	19,6	230	19900	139	16	400
LOU 08/02(683.7)	41	120	1080	10500	107	6	237
LOU 08/02(691.0)	1960	1990	752	1470	104000	80	36100
LOU 08/02(691.1)	2700	1130	1250	1180	117000	94	60600
LOU 08/02(694.7)	4740	1890	3210	4470	36000	103	79900
LOU 08/02(759.5)	30	155	98	19400	37	84	205

Figure 2. Hand specimen samples of gold-rich banded black shales with pyrite. The massive pyrite dominates the mineralogy at the hand specimen scale. (Borehole sample LOU 08/02 -694.7 upper photo; LOU08/01-7 lower photo).

3.1 Petrography and paragenesis

The paragenesis in the Lousal Mine, as deducted from the study of samples from drill holes LS08/01 and LS08/02, indicates it to be a 3 stage process: 1- open space growth, 2- recrystallization, substitution, annealing and 3- supergene alteration stage. Chlorite, silica and sericite hydrothermal halos are observed at Lousal (Fernandes, 2011; Relvas et al., 2012).

Petrographically, ore samples from the Lousal Mine are dominated at the handspecimen scale by pyrite and by cobaltite; the latter at the microscopic scale. Pyrite is present as homogeneous-looking masses in cases several centimetres in length and width although smaller grains rarely exceed 300 µm while large subhedral cobaltite grains are observed in independent clusters in the sedimentary gangue or adjacent massive pyrite grains and these are more often than not close to visible gold mineralization.

Pyrite and cobaltite coexist at the microscopic scale and petrographic relationships show them to be coeval. Subordinate pyrrhotite, sphalerite, galena, chalcocite are less common.

Pyrite and cobaltite minerals are cut by late-stage fractures that contain smaller irregular shaped grains of chalcopyrite, gold (electrum), native bismuth and bismuthinite (Fig. 3). The chalcopyrite is often replaced by (supergene) covellite in places.

These fractures are fine, irregular and often “radiate” from larger clusters of chalcopyrite that has grown in open space-filling regimes. The fractures are frequently offset and rarely exceed 10 µm in width (Fig. 3A).

Pale yellow gold (electrum) grains, which are late in the context of the ore paragenetic sequence are observed in fine fractures within the pyrite and cobaltite often as grains not exceeding 6 µm in length, half of that in thickness (Figs. 3A and B).

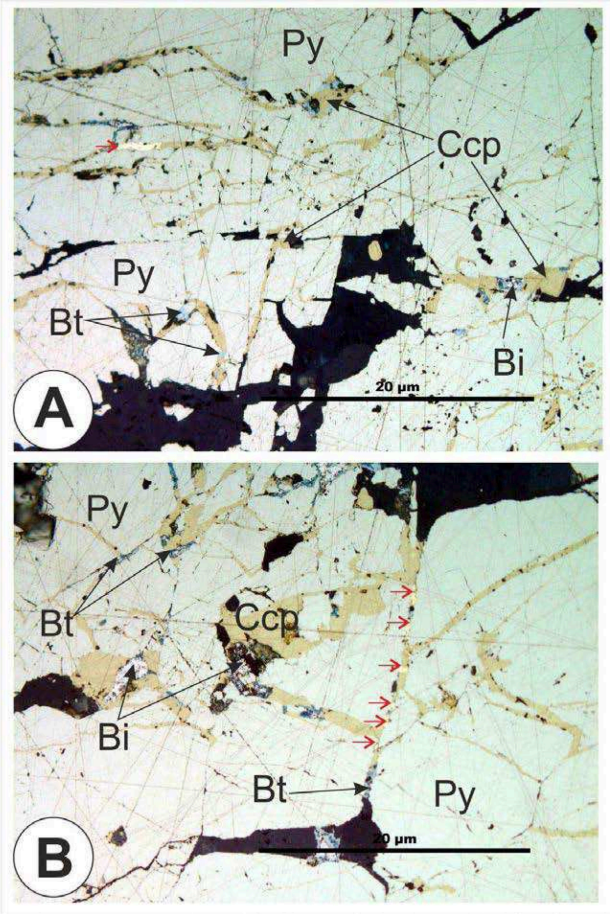

Figure 3. Photomicrographs of samples from the Lousal Mine. Py – pyrite, Ccp – chalcopyrite (with supergene covellite, vivid blue colour), Bi – native bismuth, Bt – bismuthinite, (short) Red arrows – gold (electrum). A –typical appearance of offset fractures and B- distribution of fractures from larger open space filling configuration.

3.2 EPMA characterisation

Electron-probe microanalyses (EPMA) were carried out using a fully automated JEOL JXA-8500F microprobe, equipped with one energy dispersive (EDS) and five wavelength dispersive (WDS) spectrometers. The analyses were performed with a focused electron beam of 20 kV and 20 nA incident current.

The selected analyses shown in Table 2 indicate that apart from the one sample with approximately 5 wt% Ag, most of the gold grains have a high percentage of Ag varying from 24 to 27 wt% which would classify it as auriferous electrum. Gold also contains significant amounts of Hg, Fe, and in two cases, Co as well.

Table 2. EPMA results of analysis of electrum grains in sample LS08/01-7 (732.4 m).

Element	EPMA number		
	1	2	3
Co	2.86	0.00	-
As	1.27	-	-
Ag	4.86	26.13	24.14
Hg	2.78	8.11	8.21
Au	**87.60**	**66.77**	**67.32**
Total	99.37	101.01	99.67

Ore microscopy and EPMA studies have confirmed that the gold (electrum) is genetically associated with cobaltite and native bismuth or bismuthinite (Fig. 4), an association that prevails throughout the samples studied.

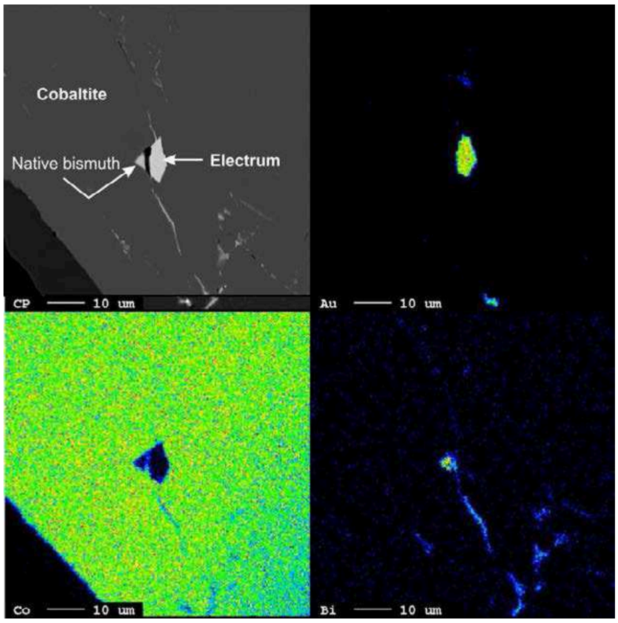

Figure 4. Element map of a region of cobaltite with late-stage fractures with native Bi and bismuthinite in association with a small grain of gold (electrum).

Additionally, the EPMA studies show that often there is also trace amounts of Te in close proximity to electrum grains and native bismuth or bismuth containing minerals.

3 Discussion

Gold (electrum) grains found in Lousal contain approximately 26 wt% Ag with Hg contents that vary from 3 to 8 wt%. One analysis detracts from this trend with only 5 wt% Ag, and therefore it will have to be further determined whether at Lousal there are two distinct gold generations although the petrographic studies coupled with the extensive EPMA do not support this theory.

There is a close association of the presence of gold with distinct zones of hydrothermal alteration characterized by chlorite, silica and ± carbonates.

EPMA results clearly indicate that the gold (electrum) occurs late in the paragenetic sequence within late-stage fractures and is closely associated with native bismuth, bismuthinite and often in close spatial association to chalcopyrite.

The Ag-rich gold is very similar to the results presented by Leistel et al (1998) in the Spanish side of the IPB. Here, two typical gold parageneses are found: 1- Gold of Co-Bi geochemical association found as electrum with abundant to common Co minerals such as cobaltite, alloclasite, glaucodot and common Bi minerals such as kobellite, tintinaite, bismuthinite and joseite associated with pyrite and/or chalcopyrite and, 2- Gold of the Zn-Ag-As geochemical association occurs in electrum and/or auriferous arsenopyrite within a more polymetallic paragenesis (predominantly Pb-Zn).

In the first type, gold mineralization occurs associated with abundant sedimentary facies and shows that the gold association formed at high temperature (>300 °C) during the initial phases of massive sulfide formation. In the Lousal mine, preliminary analogies exist with the first type of paragenesis.

There are studies that indicate that this sort of ore mineralogy is associated with the stringer zones and the interaction zones at the base of massive sulfide mounds within the IPB and not found in the overlying massive sulfides (e.g. Marcoux et al, 1996). Rare cobalt sulphoarsenides (cobaltite) are formed at the beginning of massive sulfide genesis and in a late-stage the more common bismuth sulfides (such as bismuthinite) were deposited from last-stage Cu-bearing fluids containing Bi (+ Te and Se) and gold is undoubtedly related with this last-stage phase. However, the presence of massive sulfide mounds are absent at Lousal which would favor a tectonic explanation for the presence of late-stage gold (electrum). In this case, late deformation of the massive ore represented by localized shear zones with silica remobilization and sulfides may also explain some metal (including gold, copper and bismuth) remobilization during tectonic events. Research continues.

Acknowledgements

Research was carried out within the framework of Project INCA (Characterization of Crucial Mineral Resources for the Development of Renewable Energy Technologies: The Iberian Pyrite Belt Ores as a Source of Indium and other High-technology Elements) funded by the *Fundação para a Ciência e Tecnologia* (PTDC/CTE-GIN/67027/2006) and ATLANTERRA EU Interreg Atlantic Area Project.

References

de Oliveira DPS, Guimarães FMG, Matos JX, Rosa DRN, Rosa CJP and Castelo Branco, JM, (2011). Gold in the Lousal mine, Iberian Pyrite Belt, Portugal. *In:* Barra, F, Reich, M, Campos, E., Tornos, F (eds.), Let's Talk Ore Deposits, Proceedings 11th SGA Biennial Meeting, p. 757-759.

de Oliveira DPS, Matos JX, Rosa CJP, Rosa DRN, Figueiredo MO, Silva TP, Guimarães F, Carvalho J. Pinto A, Relvas J e Reiser F (2011) The Lagoa Salgada orebody, Iberian Pyrite Belt, Portugal. Economic Geology 106, p. 1111-1128.

Fernandes A.S. (2011) Caracterização petrográfica, mineralógica e geoquímica do padrão de alteração hidrotermal a muro das massas de sulfuretos maciços do Lousal, Faixa Piritosa Ibérica. MSc Thesis Lisbon, University, Unpub. 218p

Leistel JM, Marcoux E, Deschamps Y, Joubert M (1998) Antithetic behaviour of gold in the volcanogenic massive sulfide deposits of the Iberian Pyrite Belt. Mineralium Deposita 33, p.82–97.

Matos JX, Oliveira V (2003) Mina do Lousal (Faixa Piritosa Ibérica) - Percurso geológico e mineiro pelas cortas e galerias da antiga mina. IGME, Pub. Museo Geominero, nº2, Madrid, p. 117-128.

Matos JX, Relvas JMRS (2006) Mina do Lousal (Faixa Piritosa Ibérica). Livro Guia Excursão C.4.1, VII Congresso Nacional de Geologia, Estremoz, Univ. Évora, Portugal, pp. 23-25.

Matos JX, Pereira, Z, Rosa CJP, Oliveira, JT, Relvas JMRS (2011) Late Strunian age: a key time frame for VMS deposit exploration in the Iberian Pyrite Belt. *In:* Barra, F, Reich, M, Campos, E., Tornos, F (eds.), Let's Talk Ore Deposits, Proceedings 11th SGA Biennial Meeting, p. 790-792.

Matos JX, Rosa CJP, Pereira Z, de Oliveira D, Rosa DRN, Sofia A, Relvas JMS, Oliveira, JT (in prep.) Geology and Genesis of the Lousal Volcanic-Sediment-Hosted Massive Sulfide Deposit, Iberian Pyrite Belt, Portugal.

Marcoux E, Moëlo Y, Leistel JM (1996) Bismuth and coblat minerals as indicators os stringer zones to massive sulphide deposits, Iberian Pyrite Belt. Mineralium Deposita 31:1–26.

Oliveira JT, Pereira Z, Rosa CJ, Rosa D, Matos JX (2005) Recent advances in the study of the stratigraphy and the magmatism of the Iberian Pyrite Belt, Portugal. In: Carosi, R., Dias, R., Iacopini, D., Rosenbaum, G., (Eds.,). The southern Variscan belt, Journal of the Virtual Explorer, Electronic Edition 19/9, 1441-8142.

Pereira Z, Matos J, Rosa C, Oliveira JT (2012) Palynostratigraphic importance of the Strunian in the Iberian Pyrite Belt. Joint Meeting of the 45th Annual Meeting of American Association Stratigraphic Palynology (AASP) - The Palynological Society and Meeting of Internacional Commission of Paleozoic Microflora (Cimp), Lexington, KY, USA, Abstract Book, 42-43.

Reiser FKM, Rosa DRN, Pinto AMM, Carvalho JRS, Matos JX, Guimarães FMG, Alves LC, de Oliveira DPS (2011). Mineralogy and Geochemistry of Tin- and Germanium bearing Copper Ore from the Barrigão Remobilised Vein Deposit, Iberian Pyrite Belt, Portugal. International Geology Review, 55, nº10, p.1212-1238.

Relvas, J.M.R.S., Pinto, A.M.M.; Matos, J.X. (2012) Lousal, Portugal: a successful example of rehabilitation of a closed mine in the Iberian Pyrite Belt. Society for Geology Applied to Mineral Deposits SGA News, Nº 31, June 2012, pp. 1-16.

Rosa, C Rosa, D Matos, J and Relvas, J (2010) The volcanic-sedimentary sequence of the Lousal deposit, Iberian Pyrite Belt (Portugal). Geophysical Research Abstracts, EGU General Assembly, Vol. 12, EGU2010- 11000.

Silva, EAF, Bobos I, Matos JX, Patinha C, Reis AP and Fonseca EC (2009) Mineralogy and geochemistry of trace metals and REE in volcanic massive sulfide host rocks, stream sediments, stream waters and acid mine drainage from the Lousal mine area (Iberian Pyrite Belt, Portugal). Applied Geochemistry 24, p.383–401.

Strauss G (1970) Sobre la geologia de la provincia piritífera del SW de la Península Ibérica y de sus yacimientos, en especial sobre la mina de pirita de Lousal (Portugal). Mem. ITGE T. 77, pp.266.

Strauss, GK and Beck, JS (1990) Gold mineralisations in the SW Iberian Pyrite Belt. Mineralium Deposita, 25, p. 237-245.

Strauss GK and Madel J (1974) Geology of massive sulphide deposits in the Spanish–Portuguese Pyrite Belt. Geologische Rundschau, 63, p. 191–211.