Low temperature, late Zn-Pb-(Bi-Ag-Cu) mineralization and related acid alteration replacing carbonate rocks at Cerro de Pasco, Central Peru

Regina Baumgartner, Lluís Fontboté, Ronner Bendezú
Earth Sciences, University of Geneva, Switzerland.

Keywords: Peru, epithermal, advanced argillic alteration, polymetallic Cordilleran ores.

ABSTRACT: Carbonate-hosted Zn-Pb-(Bi-Ag) ores presently being mined from areas at the eastern part of the open pit at Cerro de Pasco,Peru, contain Fe-poor sphalerite, galena, and pyrite, and display argillic to advanced argillic alteration (including kaolinite, dickite, and the alunite supergroup minerals hinsdalite and svanbergite). This Zn-Pb-(Bi-Ag) mineralization is structurally controlled and shows zoning. Cores rich in Cu grade outwards successively to pyritic zones rich in Bi-Ag-Sb (with matildite), sphalerite-galena ores, and to hematite, magnetite, siderite-rich and Mn-Fe-Zn carbonates. Crosscutting relationships indicate that the Fe-poor sphalerite stage postdates the higher temperature, Fe-rich sphalerite-galena ores spatially associated with pyrrhotite pipes long mined at Cerro de Pasco underground and in the central part of the open pit. It is proposed that the same hydrothermal stage characterized by high sulfur and oxygen fugacities and low temperatures related to E-W trending enargite veins in the western part of the open pit is responsible for the Fe-poor sphalerite-bearing Zn-Pb-(Bi-Ag) mineralization in the eastern part of the deposit.

1 INTRODUCTION

The historic Cerro de Pasco deposit, located on the Andean Plateau in Central Peru, is one of the largest polymetallic resources in the world. Past production plus known resources include a minimum of 100 Mt at about 7 % Zn, 2 % Pb and 3 oz/t Ag. In addition, mining produced 1.2 billion ounces silver, 2 million ounces Au, and Cu ores with an equivalent of around 50 Mt at 2 % Cu, largely prior to 1950.

Carbonate-hosted Zn-Pb-(Bi-Ag) ores presently being mined from the eastern part of the open pit contain Fe-poor sphalerite and display argillic to advanced argillic alteration, including aluminum-phosphate-sulfate (APS) minerals. These features strongly contrast with those of the Fe-rich sphalerite-galena ores spatially associated with pyrrhotite pipe mined underground and in the central part of the open pit for many years.

This contribution describes the Fe-poor sphalerite ores and associated acidic alteration, their distribution and structural control, crosscutting relationships with the other ore types at Cerro de Pasco, and a comparison to similar Cordilleran polymetallic replacements displaying argillic and advanced argillic alteration at Colquijirca.

2 GEOLOGICAL SETTING

The oldest exposed rocks in the Cerro de Pasco district are slightly metamorphosed Devonian shales and sandstones of the Excelsior Group. They are overlain by Permo-Triassic red beds (sandstones and conglomerates) of the Mitú Group. Over the half eastern part of the district, the Mitú Group is covered by a several hundred meter-thick Upper Triassic-Lower Jurassic carbonate sequence belonging to the Pucará Group. After multiple Eocene to Lower Miocene folding episodes, there was late-mid Miocene magmato-volcanic activity in the region (Angeles 1993). At Cerro de Pasco, like at the nearby Colquijirca District, magmatism consisted of multiple dome intrusions related to a diatreme neck with associated subsidence. At this time mineralization occurred within, but mainly along and from the eastern side of the diatreme-dome complex into the carbonate rocks of the Pucará Group (e. g., Einaudi 1977).

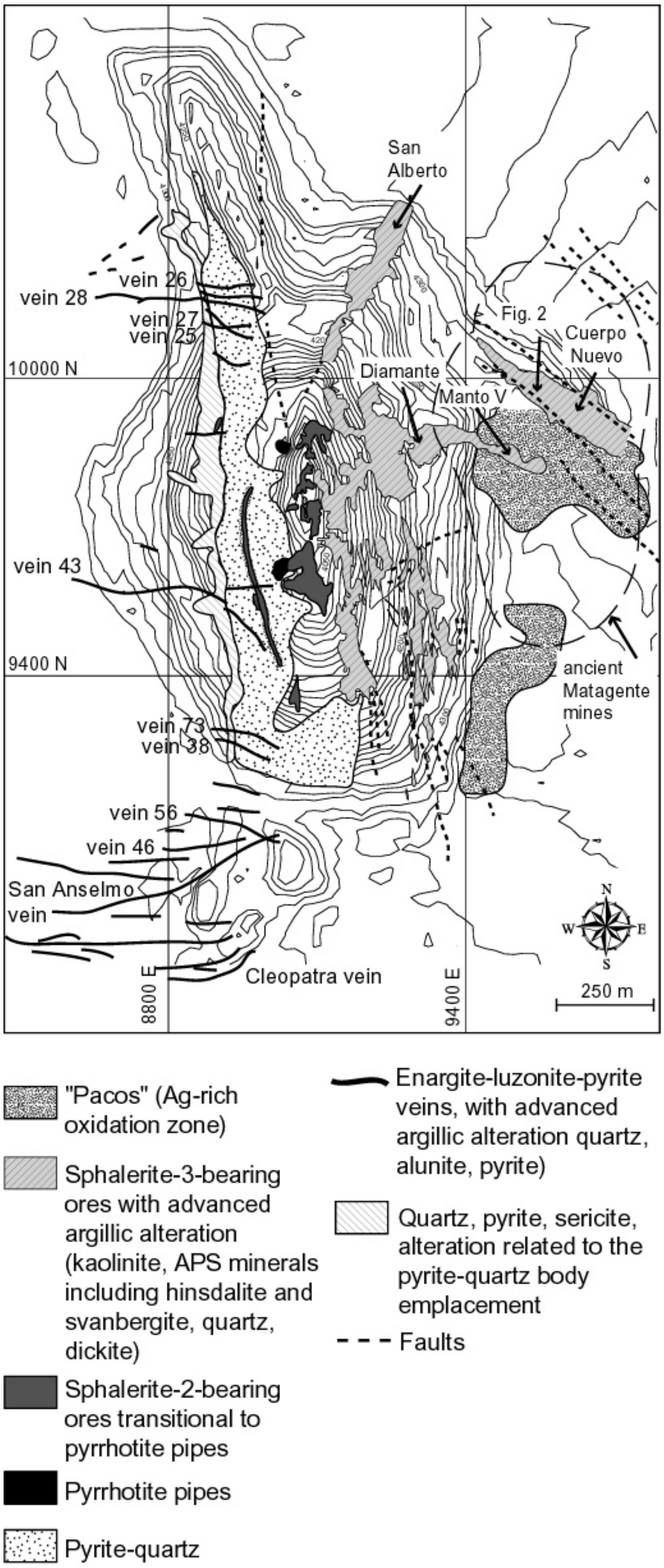

Figure 1: Distribution of Fe-rich sphalerite-2 and Fe-poor sphalerite-3 and related alteration minerals at Cerro de Pasco. Compiled and modified from Cerro de Pasco geology department documents.

3 MINERALIZATION STAGES AT CERRO DE PASCO

Integration of the work of Graton & Bowditch (1936), Lacy (1949), Ward (1961) and Einaudi (1977) with that carried out by the Cerro de Pasco geology staff allow the space-time distribution of mineralization to be established. The earliest stage formed an extensive replacement body of quartz-pyrite on the eastern margin of the vent. Only minor sphalerite was deposited during this stage. Probably as part of the quartz-pyrite stage, pyrrhotite replaced the central portions of the pyrite-quartz body in steep, pipe-like zones, grading out to ore consisting of Fe-rich sphalerite ("sphalerite 2" of Einaudi 1977, with 15 to 30% mole FeS, average 21%) and galena. E-W enargite-pyrite veins in the western area truncate this early mineralization stage. Some of these veins, largely those in the south emplaced in the Excelsior phyllites (Ward 1961), are particularly rich in Au. Einaudi (1977) also distinguished a later "sphalerite-3", with 0 to 10 mole FeS percent (average 3%) reported to be much less abundant than the Fe-rich sphalerite-2. Fe-rich sphalerite-2 was interpreted to have formed at temperatures around 250-350°C and moderate sulfur fugacity, whereas Fe-poor sphalerite-3 formed at about 200-250°C and high sulfur and oxygen fugacities.

4 "FE-POOR" SPHALERITE-3 ORES. DESCRIPTION, DISTRIBUTION AND SIGNIFICANCE

Recent development of the Cerro de Pasco deposit has shown that the Fe-poor sphalerite-3 type ores are much more abundant than previously assumed. Sphalerite-3 ores replace Pucará carbonate rocks and are mainly located in the eastern part of the open pit, including the area occupied by the ancient Matagente mines and the new Diamante, Cuerpo Nuevo and Manto V orebodies (Fig. 1). They are characterized by fine-grained (<200 μm) sphalerite-3 with a typical range of 0.4 to 4 mole % FeS (Tab. 1). Representative orebodies containing sphalerite-3 were investigated, in particular Cuerpo Nuevo and Manto V. They consist mainly of sphalerite-3, galena, and pyrite accompanied dominantly by mixtures of argillic to advanced argillic alteration minerals. Alteration minerals include the alunite supergroup APS phases hinsdalite ($(Pb,Sr)Al_3(PO_4)(SO_4)(OH)_6$) and svanbergite ($SrAl_3(PO_4)(SO_4)(OH)_6$), accompanied by abundant quartz, kaolinite, dickite, and barite, a typical mineral assemblage formed by acidic and oxidized hydrothermal fluids under 220°C (White & Hedenquist 1995).

It has further been observed that coarse grained sphalerite-3 also occurs in the central part of the deposit, in part overprinting Fe-rich sphalerite-2 ore bodies (e.g., N9860, E8920, level 1200). The common association of sphalerite-3 with kaolinite allows the easy field distinction of both sphalerite generations. Veins of "sulfide rock" also crosscut the silica-pyrite bodies in the deepest part of the western open-pit.

Table 1: Microprobe analysis of sphalerite-2 and –3 in sample CPR 315 (underground, 1200 Level, 8920-E, 9860-N). The core-rim traverses are on single grains. FeS mole% calculated from Fe wt % assuming stoichiometry.

N°	Type	Description	Fe wt %	Zn wt%	S wt%	FeS mole %
1	sl-2	Core	11.88	55.50	33.93	20.34
1	sl-3	Rim	2.29	65.58	33.22	3.88
2	sl-2	Core	5.44	61.17	33.47	9.31
2	sl-3	to	0.72	67.02	33.30	1.21
2	sl-3	Rim	0.22	66.72	33.40	0.37
3	sl-2	Core	6.19	61.07	33.05	10.51
3	sl-3		1.52	66.17	32.91	2.58
3	sl-3		0.18	67.45	33.10	0.30
3	sl-3		1.49	66.12	32.79	2.52
3	sl-3	Rim	0.72	65.94	32.87	1.22
4	sl-3	Core	0.36	67.00	32.46	0.61
4	sl-3		0.85	67.32	33.07	1.44
4	sl-3		1.15	66.70	33.53	1.96
4	sl-3		0.46	67.12	32.57	0.78
4	sl-3		0.44	66.79	32.87	0.75
4	sl-3		0.85	65.96	33.07	1.45
4	sl-3	Rim	1.16	64.99	33.06	1.98
5	sl-3	Core	1.13	66.36	33.19	1.93
5	sl-3	Rim	0.34	67.85	32.94	0.57
6	sl-3	Core	1.30	65.95	33.43	2.21
6	sl-3	Rim	0.13	67.09	32.97	0.22

5 ZONING OF "SPHALERITE-3" OREBODIES

The studied orebodies bearing Fe-poor sphalerite-3 in the Diamante, Cuerpo Nuevo, and Manto V areas display a clear zoning (Fig. 2). Well zoned orebodies typically exhibit inner cores rich in Cu (1-5 wt%). Famatinite and tetrahedrite are the principal Cu minerals in this zone, which grades outward to pyritic zones rich in Bi-Ag-Sb (occurring mainly as matildite and Bi-rich phases of the bismuthinite-stibnite series), with Bi=0.1-1%, Sb=1-3% and Ag=150-600 g/t. Zn-Pb ores (sphalerite-3 and galena) occur predominantly outside the Cu-Bi core and also contain hinsdalite, svanbergite, kaolinite, and dickite (Fig. 2). Some ore bodies do not display the internal Cu and Bi-Ag rich zones; they may occur at greater depths. In a more marginal position hematite, magnetite, and siderite-ankerite also occur, as well as Mn-Fe-Zn carbonates like oligonite and minrecordite, usually directly adjacent to the Pucará-host carbonates. These characteristics, including the presence of the alunite group minerals and Fe-poor sphalerite, are similar to those of the "sulfide rock" described by Fontboté & Bendezú (1999; 2001) and Bendezú & Fontboté (2002) at San Gregorio and Colquijirca, where they are characterized as Cordilleran base metal replacements displaying argillic and advanced argillic alteration (Bendezú et al. 2003) .

6 STRUCTURAL CONTROL OF SPHALERITE-3 ORES

"Sulfide rock" bodies at Cerro de Pasco are structurally controlled along three main directions, N45°E (San Alberto), 130° (Manto V and Cuerpo Nuevo) and 170° (southern part of Diamante), corresponding to high-angle faults. Subvertical "sulfide rock" bodies are also recognized in areas east and south of the present open pit, along 130° and 170° directions. Ore bodies are subordinately controlled by bedding (Fig. 2).

7 CONCLUSION

Our working hypothesis is that sphalerite-3 orebodies, largely associated with advanced argillic alteration (characterized by an assemblage of kaolinite, quartz, dickite, hinsdalite, svanbergite) and the E-W trending high-sulfidation enargite-bearing veins that cut the silica-pyrite body were formed during the same stage. Alunite occurring within silica-pyrite bodies in the western face of the open pit nearby enargite veins (e.g., N10275-E8860) also belong to this stage. The presence of E-W "sulfide rock"-bearing veins in the west-central part of the open pit (N9940-E9000) is consistent with this hypothesis. This is also supported by descriptions of Ward (1961) that report that some veins were mined for enargite on their deeper levels, and for galena-sphalerite in their upper portions. It appears that at Cerro de Pasco, and similar to the Colquijirca District, a hydrothermal stage characterized by high sulfur and oxygen fugacities and acidic conditions at relatively low temperature (about 200-250°C) was responsible for zoned Cu (e.g., enargite or famatinite) – Zn-Pb mineralization, essentially replacing carbonate rocks. The characteristics of this late-stage mineralization at Cerro de Pasco are similar to those of the most typical Cordilleran base-metal lode and replacement deposits (Einaudi 1982). Both at Cerro de Pasco and at Colquijirca the sphalerite of this stage is Fe-poor. At Colquijirca this stage postdates by about 460,000 years the disseminated high sulfidation gold mineralization (at Marcapunta; Bendezú et al. 2003). At Cerro de Pasco, this stage clearly postdates the silica-pyrite and iron-rich, higher temperature sphalerite-2 bodies.The temporal relationship with disseminated gold mineralization in the Venencocha area is still unknown.

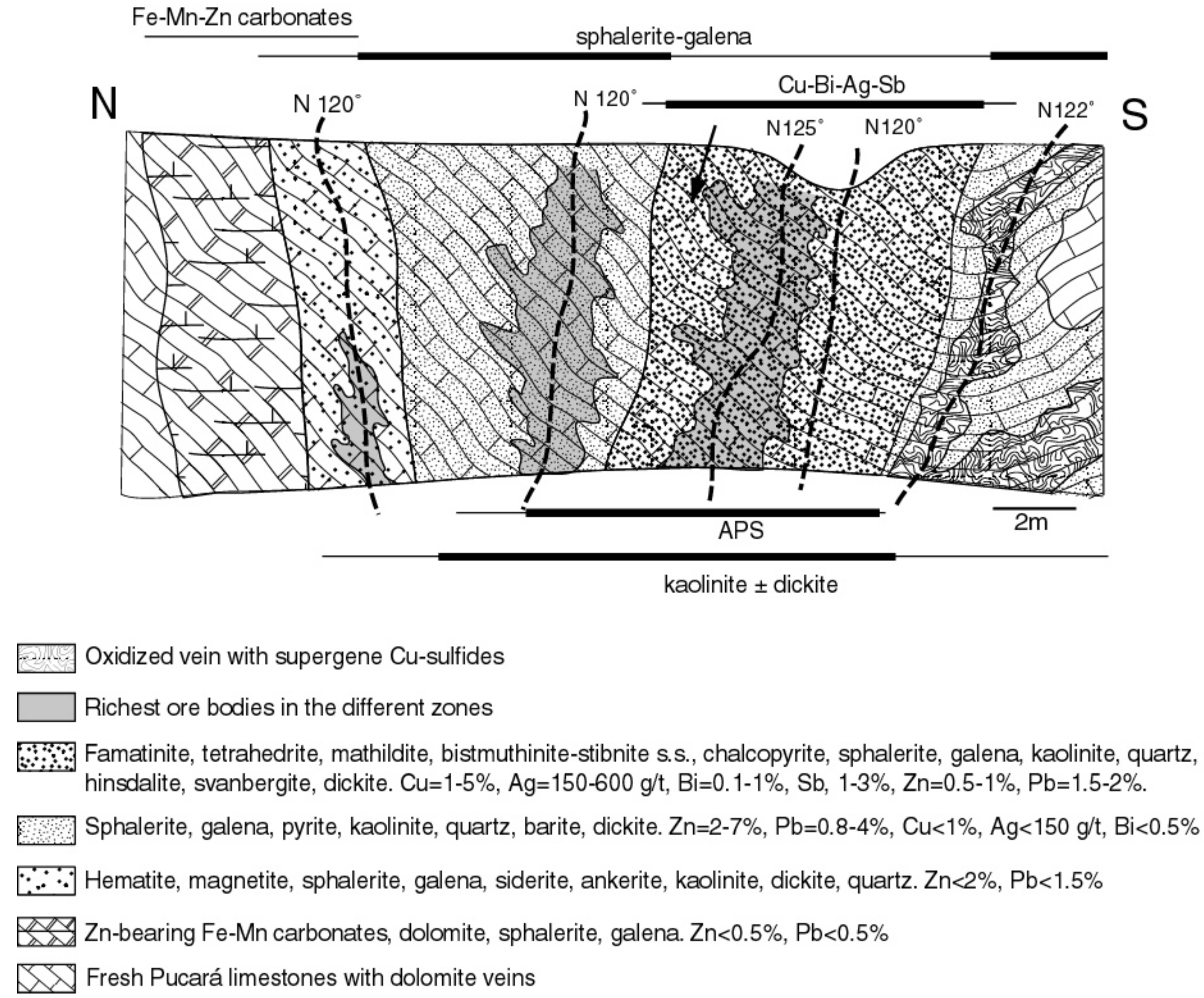

Figure 2: Cross-section of typical mineral zoning observed at a subvertical ore body at Cuerpo Nuevo (4310 bench), location in Fig. 1.

ACKNOWLEDGMENTS

The present investigation is being carried out with the support of the Swiss National Science Foundation (FN 2000-062000) and of Volcan Compañía Minera, S.A. We thank the geology staff of Volcan and COMAPSA at Cerro de Pasco for their assistance in the field as well as for helpful discussions. We thank the careful review by Jeff Hedenquist.

REFERENCES

Angeles, C., 1993. Geología de Colquijirca y alrededores. Informe privado Sociedad Minera El Brocal S.A., 39p.

Bendezú, R. & Fontboté, L. 2002. Late timing for high sulfidation Cordilleran base metal lode and replacement deposits in porphyry-related districts: the case of Colquijirca, central Peru. SGA News, v. 13, p. 1, 9-13. (also accessible under http://www.unige.ch/sciences/terre/mineral/ore/min_ore.htm).

Bendezú, R., Fontboté, L. & Cosca, M. 2003. Relative age of Cordilleran base metal lode and replacement deposits and high sulfidation Au-(Ag) epithermal mineralization in the Colquijirca mining district, central Peru. Mineralium Deposita. In press.

Einaudi, M., T. 1982. General features and origin of skarns associated with porphyry copper plutons; southwestern North America. In: Advances in geology of porphyry copper deposits; southwestern North America. Titley-S.R (ed.). p. 185-209.

Einaudi, M.T. 1977. Environment of ore deposition at Cerro de Pasco, Peru. Econ. Geol.,v. 72, p. 893-924.

Fontboté, L & Bendezú, R. 1999. The carbonate hosted Zn-Pb San Gregorio deposit, Colquijirca District, central Peru, as part of a high sulfidation epithermal system, *in* Stanley et al., (eds.), Fifth Biennial SGA Meeting, Mineral Deposits: Processes to Processing, v. 1, p. 495-498.

Fontboté, L. & Bendezú, R. 2001. The carbonate-hosted San Gregorio and Colquijirca (Zn-Pb-Ag) deposits (central Peru) as products of an epithermal high sulfidation system. ProExplo 2001, Lima, Perú, Abril 2001, CD-ROM, doc. 18 p.

Graton, L.C. & Bowditch, S. 1936. Alkaline and acid solutions in hypogene zoning at Cerro de Pasco. Econ. Geol. v. 31, p. 651-698.

Lacy, W.C. 1949. Types of pyrite and their relations to mineralization at Cerro de Pasco, Peru. Unpubl. Ph.D. thesis, Harvard University, 193 p.

Ward, H.J. 1961, The pyrite body and copper orebodies Cerro de Pasco mine, Central Peru. Econ. Geol. v. 56, p. 402-422.

White, N.C. & Hedenquist, J.W. 1995. Epithermal gold deposits: styles, characteristics and exploration. Soc. Econ. Geol. Newsletter, v. 23, p. 1, 9-13.