Factor Analysis for Metal Grade Exploration at Pallancata Vein in Peru

Jorge E. Gamarra-Urrunaga, Ricardo Castroviejo and Jesús Domínguez

1 Introduction

The epithermal Pallancata Vein is located ∼520 km SE of Lima (Ayacucho department), at ∼4,200 MASL. It crops out along 1.5 km, with N70° W strike and has a subvertical dip. Vein thicknesses are structurally controlled, both horizontally and vertically, varying from 1 m in areas of narrowing to 35 m in dilational areas [1]. The mine went into production in September 2007 and ranks sixth worldwide in silver production. It is the second largest silver mine in Peru and produced 263 t of Ag in 2011 (8.77 Moz [2]). The aim of the present study is to examine the geological information that can be gathered from the chemical data collected during the exploration of the deposit. The data are made of 35 elements which were analysed from cores of the 52 boreholes interesecting the vein. Only reliable analytical data from the vein have been used: 17 elements (*Ag*, As, *Au*, Ba, Cd, Co, Cr, *Cu*, Hg, Mo, Ni, P, *Pb*, S, *Sb*, Sr, *Zn*) have been selected, and logarithm values are used.

Two issues are relevant to this study. The first one is whether the analyses can provide a realistic picture of the evolving geochemistry of the ore solutions. The second one is the interpretation of this scenario from a metallogenic point of view and its use to support exploration. To answer the first question, a geological analysis of the vein, as well as a Factor Analysis study of the chemical data have been carried out [3]. Results from both approaches are consistent with a major mineralizing episode tightly relating Ag, Au, Pb, and Sb (*F1: Factor 1*), while Zn, Cd, and

J. E. Gamarra-Urrunaga (✉)
International Minerals Corporation, 230 South Rock Blvd, RenoNV 89502, USA
e-mail: jgamarraurrunaga@yahoo.com

R. Castroviejo (✉) · J. Domínguez
ETSI Minas, Universidad Politécnica de Madrid, c/ Ríos Rosas, 21, 28003 Madrid, Spain
e-mail: ricardo.castroviejo@upm.es

J. Domínguez (✉)
e-mail: jesus.dominguezR@upm.es

E. Pardo-Igúzquiza et al. (eds.), *Mathematics of Planet Earth*,
Lecture Notes in Earth System Sciences, DOI: 10.1007/978-3-642-32408-6_153,

Fig. 1 Ag (logaritm of ppm) isocontent contours plotted on longitudinal section along the vein. Contour values: 2.2, 2.4, 2.6, 2.8, 3.0

Cu (*F2: Factor 2*) show no relationship to the Ag grades. A discussion of the spatial distribution of Factor 1 metals shall help answer the second question.

2 Element Distribution in the Vein

The spatial distribution in the vein of selected (log)metal contents shows that the Ag grade (Fig. 1) is consistent with Au and Pb values, but not with Zn or Cu values. To explain this, a statistical analysis of all data has been carried out. Factor analysis, computed with the programme R, defines two factors: *F1*, with loadings Ag: 0.875, Au: 0.896, Pb: 0.618, Sb: 0.855. *F2*, with loadings Cu: 0.603, Zn: 0.723, Cd: 0.808, and S: 0.734. The spatial distribution of F1 (Fig. 2) is similar to that of Ag (Au) but differs from F2, suggesting unrelated events for Ag (Au) ores and for Cu, Zn sulfides (chalcopyrite, sphalerite); even if the predictive value of these plots is limited, the conclusion is consistent with textural analysis of the ores (photomicrographs: [1, 3]).

3 3 Metal Ratios, Flow Paths and Exploration

Plotting ore metal distribution in a hydrothermal vein may show the flow paths of mineralisation, particularly if (log) metal ratios are used [4, 5]. These plots are suggested to assist exploration [5, 6], since subtle changes in metal ratios may point to unknown metal concentrations. Fluid chemistry variations of the evolving hydrothermal system can be related to fluid flow, under the assumptions that (i) metal precipitation will not begin until saturation is attained; (ii) saturation and therefore precipitation will be enhanced by cooling, and this is favoured by flow of the fluids to shallower levels or by lateral flow away from the source; (iii) pressure drops or other changes related to this process may act in the same way; (iv) the temperature, and therefore the time, of precipitation of a particular metal depends not only on its solubility, but also on its concentration: the precipitation of a very diluted metal will be delayed, as compared with the saturated metal. Under these assumptions, the resulting scenario

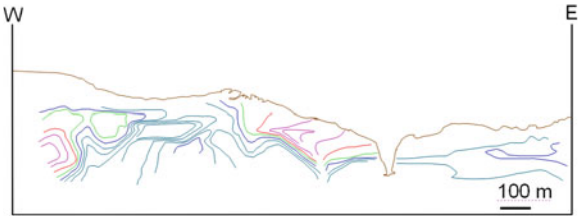

Fig. 2 Factor 1 (log) isovalue contours plotted on longitudinal section along the vein. Contour values: −1.0/0.0, 0.2, 0.4, 0.6, 0.8 − 1

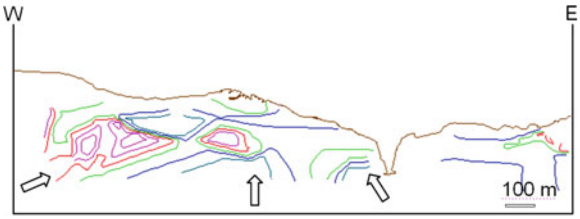

Fig. 3 Ratio logAg /logPb isovalue contours plotted on longitudinal section along the vein. Contour values: 0.9, 1.0, 1.1, 1.2, 1.4. (From chemical data in ppm)

(Fig. 3 for logAg/logPb) suggests a consistent upward flow of the hydrothermal fluids, progressing from the center and from both sides of the structure—arrows—and selectively precipitating Pb at lower levels, with a relative Ag enrichment at higher levels, consistent with known models based on experimental data [1, 7].

The spatial distribution of the ore is also reflected by the logAg/logPb ratio distribution (comp. Figs. 1 and 3). Au occurs as electrum or uytenbogaardtite, (Ag3AuS2), so it is tightly related to Ag [3], and log Au grade and logAu/logAg ratio show the same distribution as logAg grade and logAg/logPb ratio, respectively. The open loops in these log metal ratios suggests further ore to be expected in the lower center (possibly a Ag-impoverished, Pb-enriched core, consistent with current ore petrological models [1, 7]); in addition Ag is suggested westwards at deeper locations.

4 Conclusions

Factor analysis of all the data is consistent with a main event of Ag deposition (Factor 1, Fig. 2), and fits with the space distribution of metal ratios—compare Figs. 1, 2, 3,—as well as with current metallogenetic models [1, 7]. Overall geochemistry and fluid paths of the ore solutions are reflected by metal ratios (Fig. 3).The lower, open loop of the logAg/log Pb ratio distribution hints to a blind, deeper resource open for exploration.

Acknowledgments The research was funded, as part of a MSc Thesis of the first author, by EU grant ALFA II-0459FA. The authors state their thankful recollection of Prof. Enrique Chacón († 2012), UPM, for his advice and discussion of statistical data. Facilities and authorization to publish by the Co. Minera Oro Vega S.A.C. are gratefully acknowledged. Laboratory work was carried out in the *Lab^o. Microscopía Aplicada y Análisis de Imagen* (*rla* 207) of the Madrid School of Mines, UPM: funding through the Lab_Network of the Comunidad de Madrid (code UP0644) and through projects GR92-0135 and CGL2006-13688-C02-01 is also acknowledged.

References

1. Gamarra-Urrunaga, J., Castroviejo, R., & Bernhardt, H. J. (2013). Preliminary mineralogy and ore petrology of the intermediate-sulfidation pallancata deposit, Ayacucho. *Peru Canadian Mineralogist*, *51*, 67–91. doi:10.3749/canmin.51.1.67.
2. The Silver Institute, http://www.silverinstitute.org/production.php.
3. Gamarra Urrunaga, J. (2008). *Caracterización mineralógica y geoquímica de la Veta Pallancata*. Aplicaciones a la exploración minera, Parinacochas, Ayacucho, Peru. M.Sc. Thesis, Red DESIR Universidad Politécnica de Madrid.
4. Goodell, P. C., & Petersen, U. (1974). Julcani mining district, peru: A study of metal ratios. *Economic Geologists*, *69*, 347–361.
5. Castroviejo, R., Yparraguirre, J. A., & Chacón, E. (2007).Lithogeochemistry and fluid flow in the epithermal Veta Rublo base metal-silver deposit, Chonta Mine (Huancavelica, Perú). In J. Loredo (Ed.), *Exploring our environment, Proc. 23rd IAGS* (pp. 159–160). Oviedo (ISBN 978-84-690-6461-0).
6. Petersen, U., Noble, D. C., Arenas, M. J., & Goodell, P. C. (1977). Geology of the julcani mining district. *Peru Economic Geologists, 72*, 931–949.
7. Sack, R. O. (2005). Internally consistent database for sulfides and sulfosalts in the system Ag2S-Cu2S-ZnS-FeS-Sb2S3-As2S3: Update. *Geochimica et Cosmochimica Acta*, *69*, 1157–1164.