VOLCANISM AND POLYMETALLIC ORE DEPOSITS FROM SOUTHERN BOLIVIA THE CERRO BONETE MINERALIZATIONS

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RÉSUMÉ : Le Cerro Bonete, dans le district minier du Sud Lipez, contient de nombreuses minéralisations à Bi-Ag-Pb-Zn exprimées sous la forme de filons à l'intérieur de domes dacitiques à rhyodacitiques. A partir de l'étude de la mine Bolivar, il est montré que le dépôt des minéralisations et le développement d'altérations zonaires à chlorite-illite sont liés à la circulation de fluides aqueux chauds entre 350 et 200°C. Le modèle "type épithermal" n'est pas retenu.

KEY WORDS : volcanic rocks, Pb - Zn - Ag - Bi mineralizations, hydrothermal alterations, Bolivian Andes.

INTRODUCTION

Bolivia is characterized by numerous mining districts which define a roughly East-West zoning. The Western Cordillera, the Altiplano and the Eastern Cordillera can respectively be characterized by Cu - Mo - Au - Fe, Cu - Pb - Zn - Ag - Au and Sn - W - Bi - Ag - Au mineralizations. Five districts are usually distinguished in the Eastern Cordillera (Sugaki et al, 1986), with from north to south, the La Paz (Sn - W), the Oruro (Sn), the Potosi (Sn - Ag), the Quechisla (Sn - Ag) and the Lipez (Pb - Zn - Ag - Bi) districts.

The Cerro Bonete mineralizations belong to the Lipez district, at the southernmost part of the Altiplano, near the Argentinian border. In this area, numerous small deposits and showers are known since the Spanish times, and sometimes mined. They are hosted by volcanic formations and wall-rock alteration is observed. Accurate mineralogical, geochemical and fluid inclusion studies were performed on three small mines and showers, among them the Bolivar mine, in order to know the nature of the mineralizations, the alterations products and the mechanisms of ore deposition ("epithermal type" or not).

GEOLOGICAL SETTING

In the sudied area (fig.1), the oldest formation, the Potoco formation, consists of continental conglomerates of Eocene to lower Oligocene age, with interbedded gypsum. It is unconformably overlain by the fine-grained sandstones of the San Vicente formation (Middle to Upper Oligocene). The Rondal formation corresponds to the first volcanic stage. It appears in the field as flows, sills and dykes of mafic rocks, emitted between 23.5 and 21 Ma (Kussmaul et al, 1975 ; Fornari et al, 1989). There are unconformably covered by the Quehua tuffs of Middle to Upper age, which are thick aerial explosive products emitted from various vents, with an interbedded conglomerate level.

They are intruded by several dacite domes, the Cerro Bonete, the Cerro Colorado or the the Cerro Morokho towards the west, for example, which, in the area, host numerous Pb - Zn - Ag - Bi mineralizations such as the Bolivar mine. According to Kussmaul et al (1977) data, these domes would have a Miocene age.

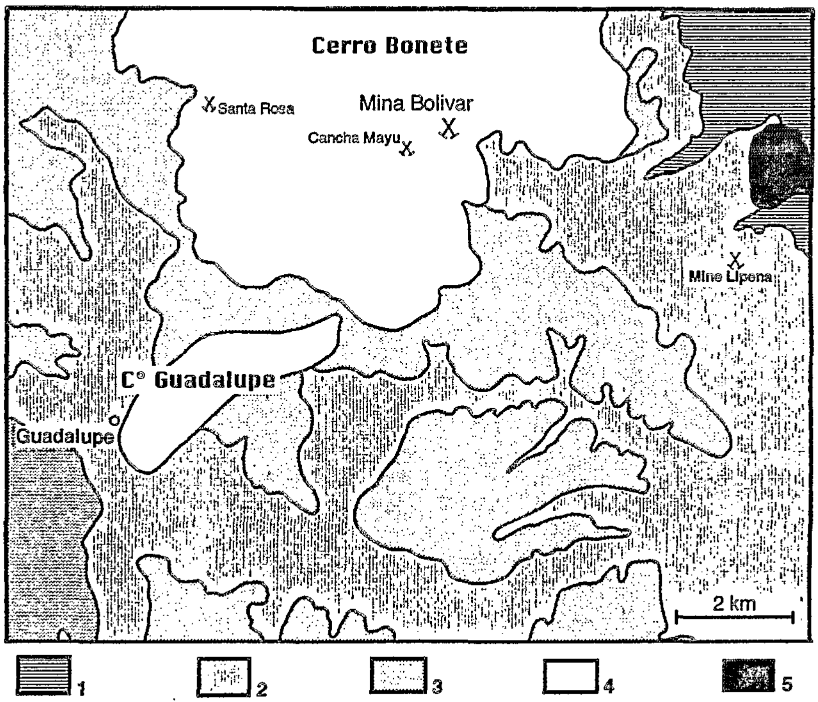

Fig.1 - Simplified geological map of the Cerro Bonete area (from unpublished Orstom La Paz report, 1989)
1 - San Vicente formation ; 2 - Rondal lavas ; 3 - Quehua tuffs ; 4 - intrusive domes ; 5 quaternary

PETROLOGY OF THE HOST FORMATIONS

The host rock of the mineralization in Bolivar mine is a rhyodacite (fig.2) with 36 vol% phenocrysts, plagioclases (8-19 vol% ; An40-55), biotite (> 9 vol% ; X_{Fe} between 0.3 and 0.4 ; $Al^{(IV)}$ = 0.25), quartz (1.5-6.5 vol%) and chloritized amphiboles. Microlites are observed in the matrix. They consist of quartz, Ca rich plagioclases (An55-66) and accessory minerals (Fe-Ti oxides and Fe sulfides). These rocks are peraluminous and characterized by medium SiO_2 (62.1-65.4 wt%) and alkalis (Na_2O +K_2O = 5.4 - 7.1 wt% with Na / Na+K = 0.43-0.51).

MINERALIZATION

The ore deposit corresponds to a 10-25 cm thick main vein (N86°W), mined by COMIBOL up to 1979. It is hosted by one of the various domes which compose the Cerro Bonete complex. The main ore mineralization consists of pavonite ($AgBi_3S_5$), bismuthinite with pyrite and chalcopyrite with an average grade of 0.3% Bi, 0.2% Pb and 300g/t Ag (Richter et al, 1992).

The mineralization sequence (fig.3) can be divided into three stages characterized by the main following associations :

- stage 1 : arsenopyrite - pyrite 1
- stage 2 : pyrite 2 - chalcopyrite - Bi-Ag minerals (pavonite, bismuthinite, emplectite, aikinite)
- stage 3 : pyrite 3 - galena - sphalerite - grey coppers - marcasite - carbonates

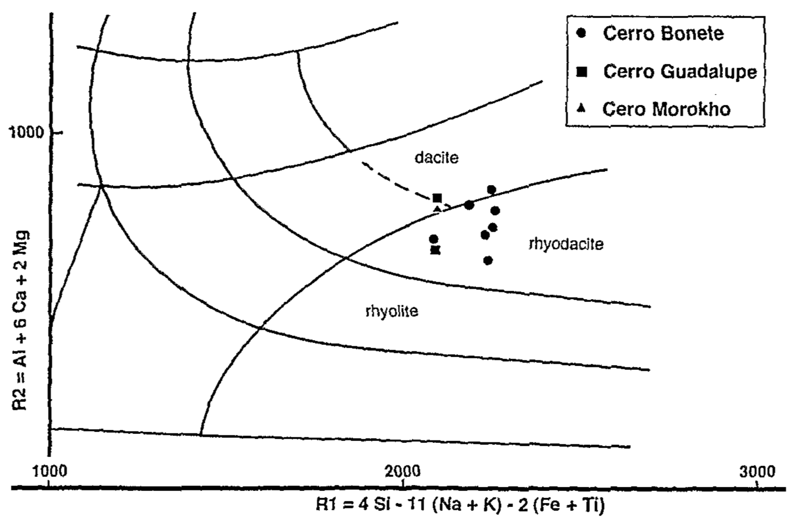

Fig. 2 - Cerro Bonete rhyodacite in a R1-R2 diagram (La Roche et al, 1980).

The R1-R2 diagram combines the chemical composition of the whole rocks and the chemical data on their minerals. It includes all the major elements as millications, a mineralogical network, the degree of silica saturation and the combined changes in the Fe / (Fe + Mg) and (Ab + Or) / An ratios in igneous rocks.

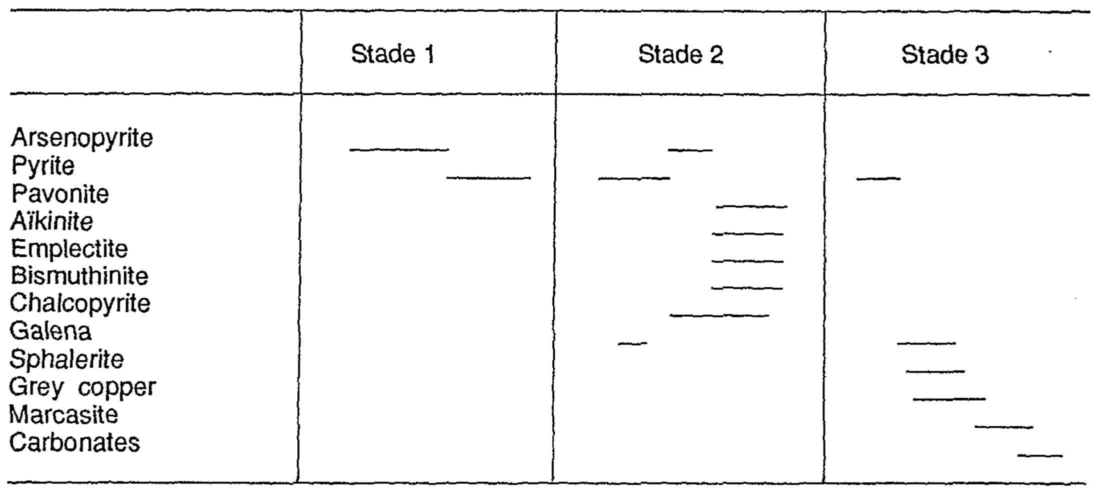

Fig.3 - Mineralogical sequence observed at Bolivar mine

WALL - ROCK ALTERATION

The surrounding rhyodacite is altered in relation with the ore deposition. It was sampled up to 30 m from the mineralized vein in order to determine the nature of the alteration minerals and their space - time evolution. In contact to the vein, the primary plagioclase - biotite association is replaced by a dominant illite - subordinated chlorite association. Two chlorite crystallization stages separated by the illite development are observed. In getting farther away from the vein, the chlorite content increases and the illite one decreases. Few smectites appear. Simultaneously, the X_{Fe} for both chlorites and illites decreases, respectively 0.3 - 0.4 instead of 0.9 - 1.0 and 0.3 - 0.4 instead of 0.67, and the phengitic substitution of illites tends to increase. Such time - space zoning is observed in the three studied places (Bolivar mine, Cancha Mayu and Santa Rosa showers).

TEMPERATURE CONDITIONS

The temperature of the alteration was determined using the chlorite thermometer (Cathelineau, 1988) and fluid inclusion studies. Chlorite crystallization temperatures vary from 280 - 350°C, near the vein, to 210 - 260°C, 30 m away from the vein. The related fluids are aqueous and the fluid inclusion studies confirm these temperatures with T ranging from 360°C to 180°C according to the fluid stage.

CONCLUSIONS

In conclusion, all the mineralized zones hosted by the various rhyodacite domes which compose the Cerro Bonete are rather similar. This indicates similar conditions for alteration development and ore deposition. The temperatures (350°C to 200°C) indicate medium to low temperature hydrothermal systems. The alteration minerals are the same (nature, composition, space and time zoning) as the ore minerals (Bi - Ag - Pb - Zn paragenesis). According to the nature of the newly-formed minerals, these mineralized zones cannot be related to a typical "epithermal type" deposit.

REFERENCES

CATHELINEAU, M., 1988, Cation site occupancy in chlorites and illites as a function of temperature. Clay Minerals, 23, 471-485.

FORNARI, M., HERAIL, G., POZZO, I.L. y VISCARRA, G.,1989, Los yacimientos de oro de Los Lipez (Bolivia) tomo 1 : Estratigrafia y dinamica de emplazamiento de los volcanitas del area de Guadalupe. ORSTOM en Bolivia, n°19, La Paz.

KUSSMAUL, S., JORDAN, L. and PLOSKONKA, E., 1975, Isotopic ages of Tertiary volcanic rocks of SW Bolivia. Geol. Jahrb., 14, 111-120.

KUSSMAUL, S., HORMANN, P.K., PLOSKONKA, E. and SUBIETA, P.,1977, Volcanism and structure of southwestern Bolivia. J. Volcan. Geotherm. Research, 2, 73-111.

LA ROCHE, H. de, LETERRIER, J., GRANDCLAUDE, Ph. and MARCHAL, M., 1980, A classification of volcanic and plutonic rocks using a R1-R2 diagram and major elements analyses. Its relationships with current nomenclatures. Chem. Geol., 29, 183-210.

RICHTER, H.D., LUDINGTON, S., BROOKS, W.E., BRAY, E.A. (du), ENRIQUEZ-ROMERO, R., BAILEY, E.A., HINIJOSA-VELASCO, A. SORIA-ESCALANTE, E. and ESCOBAR-DIAZ, A., 1992, The Cerro Bonete area. U.S.G.S., Bull.,1975, 166-174.

SUGAKI, A., UENO, H., SHIMADA, N., KITAKAZA, A. HAYASHI, K., SANJINES, O.V. and VELARDE, O.V., 1986, Geological study on the ore in the Sur Lipez district, Bolivia. Sci. Rept. Tohoku Univ., 3, 16, 327-352.