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Mineralizations of the Lavalleja Group (Uruguay), a Probable Neoproterozoic Volcano-sedimentary Sequence

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Abstract

The Lavalleja Group is located in the southern extreme of the Dom Feliciano Belt, being tentatively correlated with the Porongos and Brusque Groups of Brazil. The basement of the Lavalleja Group is probably represented by granitic-gneissic rocks of the Campanero Unit with ages, in the southern portion, ranging from 1.75 to 2.1 Ga (U-Pb in zircon). The Lavalleja Group is characterized by narrow bands of metasedimentary and metavolcanic rocks and it is separated in three formations, namely (from base to top): Zanja del Tigre, Fuente del Puma and Minas. Outcrops assigned to the Minas Formation have been recently correlated with the Arroyo del Soldado Group. Only the Fuente del Puma formation hosts base metals, Au and Ag ocurrences. The Fuente del Puma formation is divided into three informal units: sedimentary, volcanic and hornblenditic gabbros. The sedimentary unit is characterized by an important amount of carbonates. Syn-collisional to postectonic granitic bodies (Carapé Complex) intrudes the Lavalleja Group and the Campanero Unit.

Several mineralizations are located in the Fuente del Puma Formation, those associated to Arrospide, Ramallo-Reus, Chape, Valencia, La Oriental, Apolonia, Redondo Hill, La China and La Paloma mines are the most important. In addition, many ocurrences of Cu-Zn-Pb were recognized in the region. The Cu-Zn-Pb mineralization includes massive sulfides with pyrite-chalcopyrite-sphalerite-galena-pyrrothyte, arsenopyrite-hematite into small bodies with lenticular shape. The host rock shows frequently hydrothermal alteration. The geochemistry and the geological features of the mineralizations suggest Besshi Massive Sulphide Zn-Cu-Pb and SEDEX Zn-Pb as most probably genetic models for the deposits related to the Neoproterozoic orogeny. Early mineralizations are syngenetic and were formed on the sea floor, although the main mineralizations are related to remobilization during syn- to late-metamorphic events and thrusting.

Key words: Neoproterozoic, Brasiliano, Mineralizations, SEDEX Zn-Pb, Besshy type.

Introduction

The Lavalleja Group, which is exposed along the Dom Feliciano Belt is located in the southeast of Uruguay and is represented by metavolcano-sedimentary rocks (Fig. 1). It was developed during late Proterozoic-early Paleozoic Brasiliano orogeny. Based on geochemical signature of the magmatic rocks of the Lavalleja Group, mainly metagabbros, basic and acidic metavolcanic rocks, a back-arc basin tectonic setting is suggested by Sánchez-Bettucci et al. (2001). The Lavalleja Group was divided into the Minas, Fuente del Puma and Zanja del Tigre Formations by Sánchez-Bettucci (1998) and Sánchez-Bettucci and Ramos (1999). The Minas Formation is represented by arkoses, quartzites, pelites, and carbonates, and has been correlated with the Arroyo del Soldado Group (Gaucher et al., 1996; Gaucher, 1999, 2000; Gaucher et al., 2004). The Fuente del Puma Formation is represented mainly by pelites, calcopelites, siltstones, limestones, sandstones and mafic to felsic volcanic rocks. The Zanja del Tigre Formation includes quartzites, micaschists, metagabbros, amphibolites, gneisses and marbles. Lithologies belonging to this unit were included by Bossi and Navarro (1991) in the Carapé Group (Sánchez-Bettucci et al., 2003).

The metamorphic grade increases to the southeast, ranging from very low grade to lower greenschist facies in the Minas Formation, to upper greenschist-lower amphibolite facies in the Fuente del Puma and Zanja del

Tigre Formations (Sánchez-Bettucci and Ramos, 1999; Sánchez-Bettucci et al., 2001). The metamorphic mineral assemblages correspond to a low-pressure regional metamorphism associated with a high thermal gradient (Sánchez-Bettucci et al., 2001).

A compressive deformational event, which corresponds to the closure of the Lavalleja Basin, was recognized. The petrology, geochemistry, metamorphic grade and tectonic setting are consistent with a back-arc basin for the Lavalleja Group (Sánchez-Bettucci et al., 2001).

The basement of the Lavalleja Group is represented by the Campanero Unit which is constituted by pretectonic granitoids conforming heterogeneous bodies that share effects of deformation. This granitoids have variable texture from gneissic to mylonitic. Their characteristic feature is an outstanding mylonitic foliation related to recrystalization phenomena (blastesis). Several facies commonly show biotite bands (schlieren) (Sánchez-Bettucci, 1998). U/Pb dating made on the Campanero Unit have yielded Paleoproterozoic ages.

The aim of this study is to constrain the tectonic, volcanic and sedimentary environment that prevailed during formation of the mineralizations related to the Fuente del Puma Formation. These mineralizations are an example of Neoproterozoic deposits in a back-arc basin in Southeastern Uruguay.

Geological Framework

The Fuente del Puma Formation (Fig. 2) is a low-grade metamorphic sequence composed of sedimentary protoliths interbedded with basalts, rhyolites, andesites, and mafic to felsic tuffs. The volcanic rocks show breccia and pillow structures and the primary igneous texture is usually

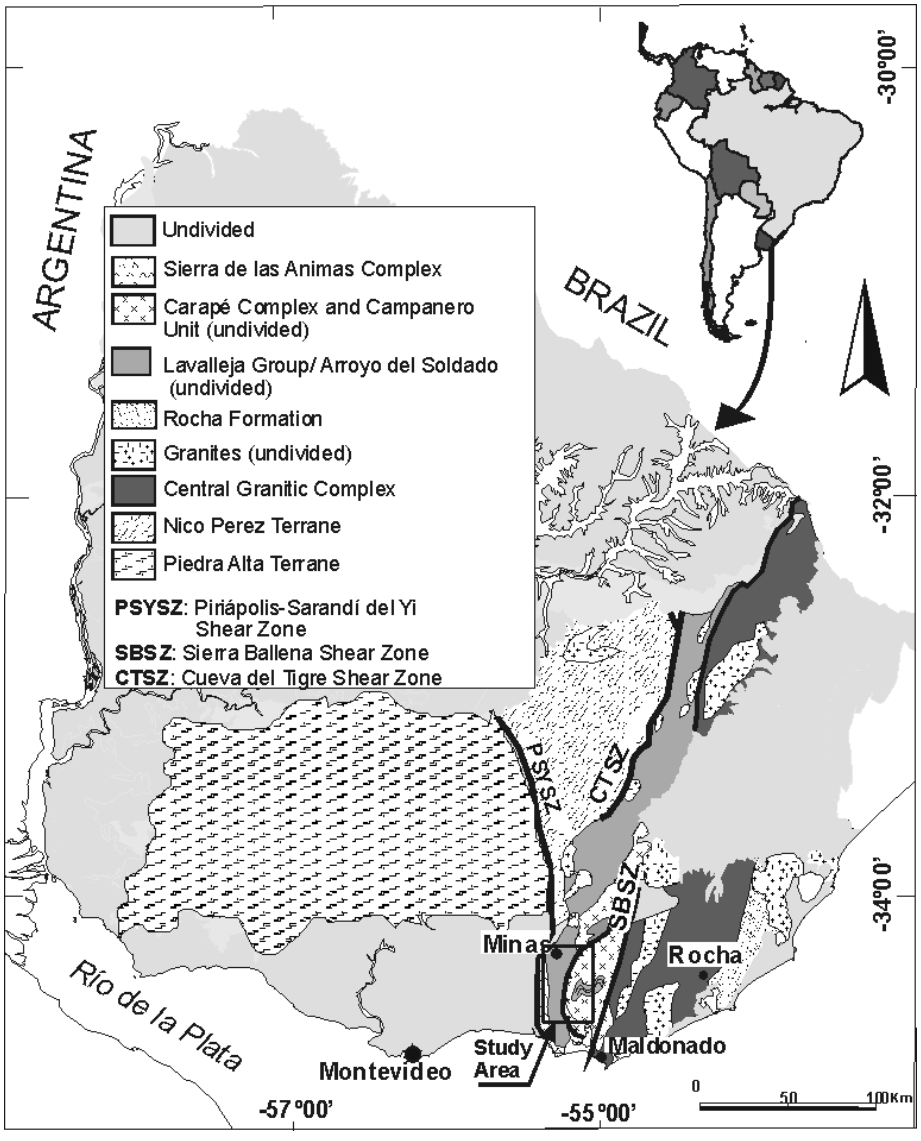

Fig. 1. Location of the study area in a simplified geological map of Uruguay, showing the most important Late-Proterozoic units (modified from Sánchez-Bettucci, 1998).

preserved (Sánchez-Bettucci, 1998; Sánchez-Bettucci et al., 2001; Oyhantçabal et al., 2001). In addition, numerous gabbroic dykes and small concordant bodies occur.

Volcanic rocks range from basalt through andesites to dacites and rhyolites. The rhyolites are alkaline while the basic rocks show a tholeiitic to calc-alkaline trend. The more conspicuous feature of this volcanic suite is their bimodality, which reflects mixed eruptive and compositional styles between a volcanic arc and back-arc basin (Sánchez-Bettucci, 1998; Sánchez-Bettucci et al., 2001). The diagrams of rare earth elements from volcanic rocks show two different patterns, a relative flat pattern, resembling MORB rocks; and the other one, with different degrees of enrichment in light REE but depleted in high REE, which could correspond to a suprasubduction environment of an oceanic basin floor with initial MORB magmatism. Sánchez-Bettucci et al. (2001) suggested that subcontinental lithosphere was implicated in the genesis of these igneous rocks.

From west to east, the volcanic rocks of the Fuente del Puma Formation show marked polarity: a deep facies, mainly basaltic pass gradually to shallower, represented by acidic pyroclastic rocks, at the east.

The stratigraphy of the Fuente del Puma Formation hosting mineralization consists of three main units. *Unit* A is represented by a thick sequence of interbedded marine mudstones, siltstones and sandstones interbedded with submarine tuffs and basaltic to andesitic lava flows with

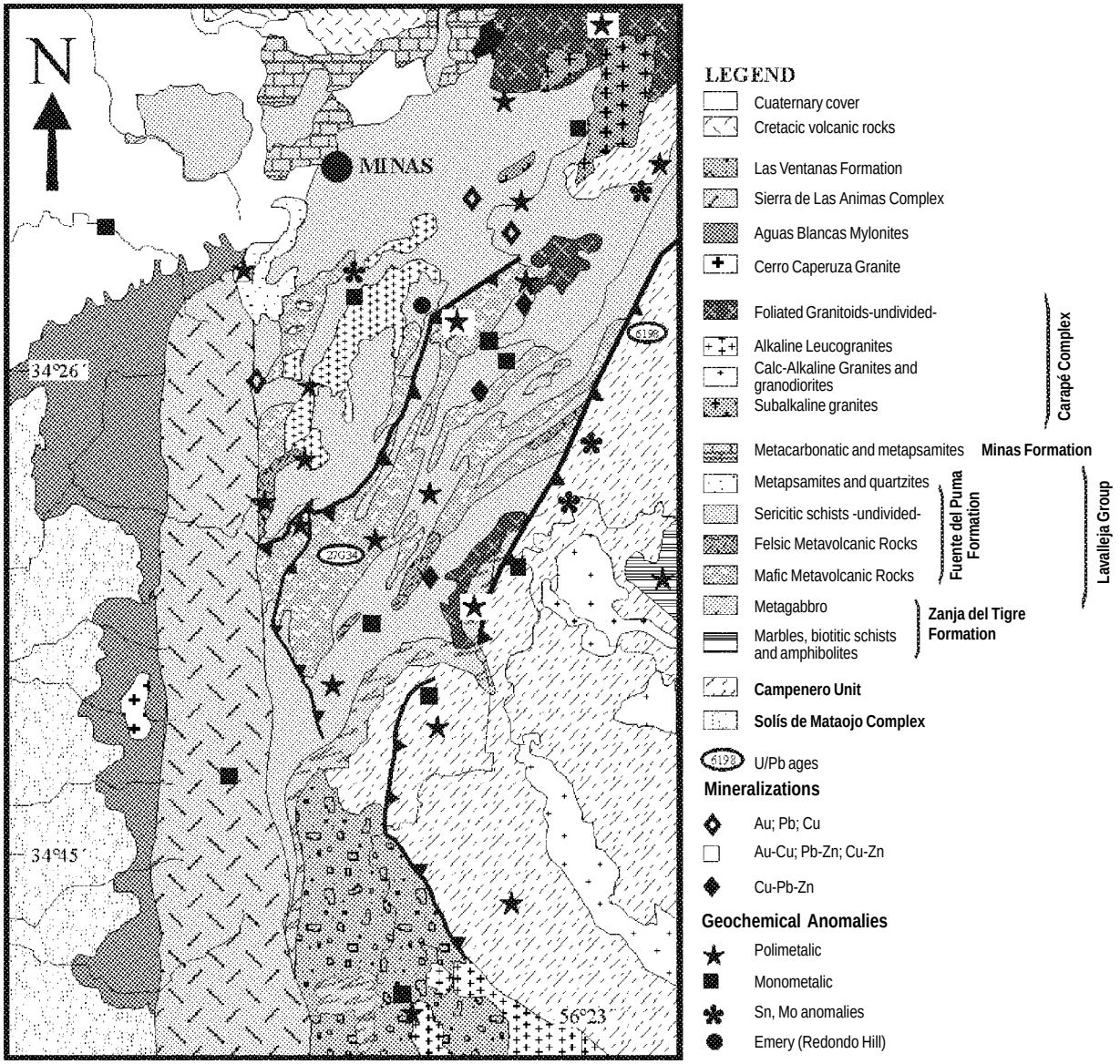

Fig. 2. Geological sketch of the study area showing the locations of mineralizations in the Fuente del Puma Formation (Lavalleja Group) (modified from Sánchez-Bettucci, 1998).

calc-alkaline and tholeiitic affinities. Towards the top of this unit, basaltic and andesitic lavas, hyaloclastic breccias and peperites become predominant and indicate increasing and more proximal volcanic activity. In addition, a dense network of gabbroic sills intrudes the *Unit* A. The overlying *Unit* B (nearby *La Oriental Mine)* is characterized by bimodal volcanism. This unit consists of submarine metavolcanic rocks and pyroclastic deposits ranging from basaltic-andesitic to rhyodacitic composition interbedded with metavolcaniclastic sandstones, tuffaceous mudstones, metasiltstones, and impure metalimestones. The overlying *Unit* C consists of similar assemblages than found in the underlying *Unit* B, but contains more abundant felsic volcanic rocks. Shallow marine volcanics and dolostones, limestones predominate in this unit.

The mineralizations are coeval with bimodal volcanism and carbonatic sedimentation, but remobilization during late Brasiliano brittle tectonic events could be an important control in the genesis of these mineralizations.

The gabbroic subvolcanic stocks observed may suggest the presence of relatively high crustal magma chambers at the time of mineralization, which could have generated the local heat-flow necessary to activate seawater convection cells into the volcanosedimentary sequence.

Geochronology

From the geochronological point of view, the scarcities of datings in the Lavalleja Group suggest us to be prudent with the interpretation. Gomez Rifas (1995) reports K/Ar ages in whole-rock of four metabasalts but did not make any interpretation of the data. These ages are: 626±47 Ma, 750 Ma and 1203±65 Ma. The analyzed samples in fact correspond to metagabbros. Sanchez-Bettucci and Ramos (1999) report a K/Ar age of 714±10 Ma in Gomez Rifas's "metabasalt" of Fuente del Puma Formation. Mallman (2002) assumes (*sic*) a crystallization age of 1200 Ma to calculate an initial $^{87}Sr/^{86}Sr$ ratio, and obtains values between 0.705–0.707. By Sm-Nd method, this author determines for metasedimentary and metavolcanic rocks a TDM model age ranging from 1738 to 2900 Ma. Basei et al. (2001) show Nd model ages for Dom Feliciano Schist Belt ranging from 1.5 to 2.4 Ga with a mean value of 1.91 Ga.

Different types of granitoids represent the basement (Campanero Unit). Sánchez-Bettucci (1998) suggested that these rocks are regionally deformed, though not all in the same way, based on the analysis of mineralogy, protoliths and structure. The analyzed rocks are protomylonitic medium-grained biotite granite with K feldspar and subordinate plagioclase. The U-Pb age on zircon from mylonitic granite is 1735±32 Ma. The analytical data are shown in table 1 and the Concordia diagram in figure 3.

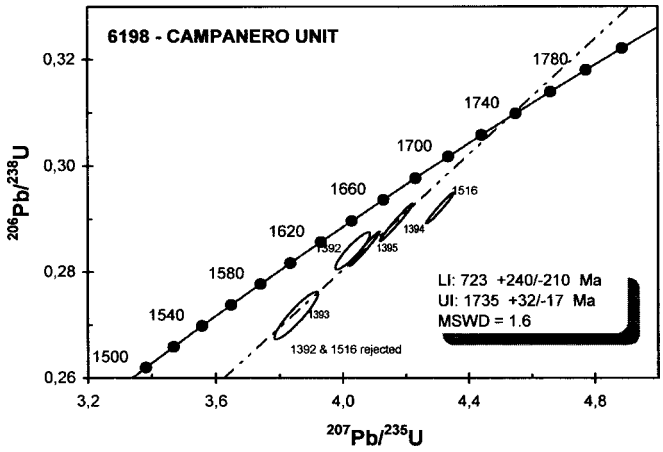

Fig. 3. U/Pb Concordia of Campanero Unit (sample 6198, mylonitic granite).

Mineralizations

Some well-known old mines are La Oriental (Cu), La Constancia (Cu), Apolonia (Cu-Pb), Chape (Cu-Pb), Ramallo-Reus (Cu-Pb), Valencia (Pb-Zn-Mn) and La China (Ba-Cu). These have been object of mining mainly during second half of the eighteenth century and exploration during first half of the nineteenth century. The available data about tonnage and concentration determine that they can not be considered ore deposits.

The mining resources in Uruguay were studied by Marstrander (1914), who elaborated a succinct manuscript describing this region. This author mentioned iron ores and gold in sediments of San Francisco, San Antonio and Campanero streams. Guillemain (1911) pointed out the existence of Galena, Chalcopyrite, Bornite, native Gold, Copper and, Tetradymite (Bi_2Te_2S). Walther (1932) suggested that the associations Au-Cu-Pb in the region are related to intrusive apomagmatic bodies. McMillan (1933) mentioned Mn exploitation associated to schist. Bossi (1978) presented a detailed review of the mineralizations related to the Lavalleja Group. Midot (1984) suggested that the mineralizations are associated to the Fuente del Puma Formation. La Oriental, Reus and Chape mines are placed in calcpelitic and metapelitic levels interbedded with basic volcanic rocks. Minor ocurrences of jasper and "*Chapeau de fer*" are also present. Preciozzi (1989) distinguished three types of mineralization following Midot (1984) proposal, the first one corresponds to massive sulfide deposits associated to volcanism; the second one associated with limestones and the last one associated with thrusting.

The Ramallo-Reus lead mine is located in the vicinity of Arroyo Minas Viejas, 10 km south of Minas town. The mineralization was located at 20 meters depth. Marstrander (1915) suggested the presence of silver.

Table 1. U/Pb analytical data for the Campanero Unit.

SPU	Fract.	Zircon typology	$^{207}Pb/^{235}U$	Error (%)	$^{206}Pb/^{238}U$	Error (%)	$^{207}Pb/^{206}Pb$	Error (%)	$^{206}Pb/^{204}Pb$	Pb (ppm)	U (ppm)	Weight (mg)	$^{206}Pb/^{238}U$ Age (Ma)	$^{207}Pb/^{235}U$ Age (Ma)	$^{207}Pb/^{206}Pb$ Age (Ma)
6198 – Mylonitic granite															
1392	1	P(3X1), tr, bt, cl	4,03125	1,12	0,284025	1,01	0,102939	0,481	706,13	5,25	14,74	134,22	1611	1640	1677
1393	3	P(3X1), tr, bt	3,85235	1,47	0,271805	1,35	0,102794	0,58	234,96	16,44	40,55	0,08385	1550	1603	1675
1394	4	P(2X1), tr, bt, cl	4,16971	1,03	0,28942	1,01	0,104491	0,189		15,74	39,83	0,15153	1638	1668	1705
1395	5	P(2X1), tr, bt, cl	4,06894	0,959	0,284437	0,945	0,103751	0,163	321,58	23,34	57,54	0,0765	1613	1648	1692
1516	6	P(2X1), tr, bt, cl	4,30827	0,835	0,292087	0,818	0,106977	0,173	315,73	39,15	91,32	0,04136	1652	1695	1748

The Valencia lead mine is located 5 km south of Minas town. A galena vein in dolomitic host rock (Marstrander, 1915) represents the mineralization. The Pb-Zn and Mn mineralization is placed in carbonates and jaspers respectively, associated to the sedimentation in the margin of the basin (Midot, 1984).

The Arrospide gold mine is located 7 km to the east of Minas town, nearby Arroyo Campanero Chico. The mineralization is represented by gold and gold-bearing pyrite in a quartz vein, hosted by a metagabbro.

The Apolonia Mine, according to information of Avé Lallement (1884) presents a copper mineralization with pyrite, chalcopyrite, galena and magnetite in basic volcanic rocks. Pena et al. (1987) point out the presence of sphalerite. The detailed geochemical study of the Apolonia mine defines Cu, Pb, Zn, As, Ni, Ba, V and Mn anomalies and a geochemical association Cu-V with tenors of 177 to 376 ppm respectively (stream sediments). In addition, they found high Zn (131 ppm) and As (51 ppm) values. According to Midot (1984), the mineralization is related to epidote-rich rocks with rounded to euhedral cordierite and galena in microfissures, hematite and subordinate quartz. This author suggested that the origin of the cordierite is younger than regional metamorphism and could be the product of contact metamorphism of granitic plutons. The Cu mineralization would be proximal-type disseminated, and hosted in a chlorite and quartz rich stockwork. The mineral association is pyrite, sphalerite, chalcopyrite, galena, magnetite and hematite.

In the La Paloma mine, the Cu occurs in calcareous rocks nearby the valley of the Río San Francisco and Arroyo Mataojo de la Sierra.

The La Oriental mine is located nearby La Mina stream, 20 km south of Minas town. The mineral association is magnetite, chalcopyrite, sphalerite, pyrrotite (altered to marcasite) with pentlandite (iron nickel sulfide) intergrowths, arsenopyrite, pyrite (birds-eye structure), bornite, galena and covellite. According to Midot (1984) the mineralization is located in tectonic breccias (Fig. 4) with abundant iron oxides, malachite, azurite, chlorite and quartz fragments, in which the primary lamination is microfolded. Preciozzi (1989) proposed that the mineralization of this mine corresponds to a massive sulfide deposit. The mining was made in a breccia along a thrust fault, which concentrated the mineralization.

The Chape mine is located 13 km southeast of Minas town. The mineralization consists of galena, pyrrotite, sphalerite, and pyrite in quartz veins in a metagabbro host rock. This deposit occurs in thrust fault zone.

The La China mine is located 3 km east of Minas town. The mineralization occurs as barite cement in a

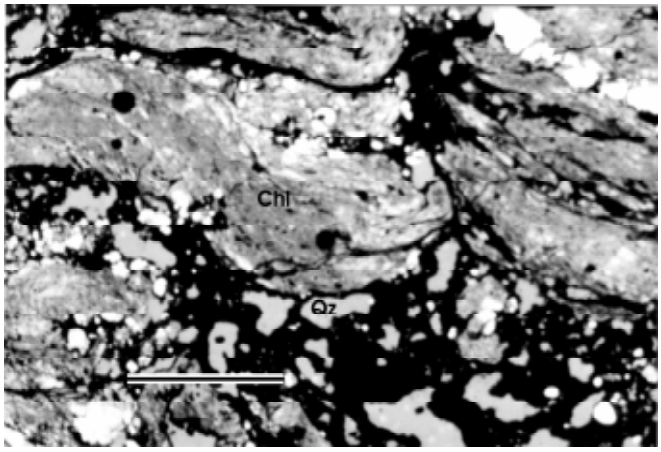

Fig. 4. Photomicrograph of chloritic Breccia with oxided sulfides (La Oriental mine). Chl: chlorite, Qz: quartz. Scale bar represents 1 mm, PPL.

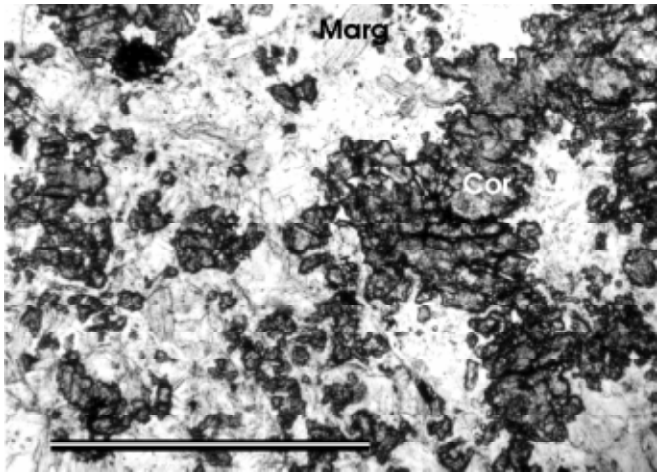

Fig. 5. Photomicrograph of corundum rich rock. Crystals of corundum (Cor), margarite (Marg). Redondo Hill mine. Scale bar represents 1 mm, PPL.

conglomerate, associated with pyrite, marcasite, sphalerite and galena. Field relationships suggest a syn-sedimentary origin. Barite-rich rocks (baritites) are commonly lateral distal equivalents of shale-hosted Pb-Zn deposits. The barite was deposited on the seafloor and close to submarine hydrothermal vents, or more distal cherts, hematite-chert iron formations, silica and manganese-enriched sediments (Paradis, 1997).

The Cerro Redondo emery mine is located 5 km to the south of Minas town. It presents a rounded shape (60 m high and 300m diameter). The mineral association is corundum and margarite with diaspore and muscovite in veins (Fig. 5). This epithermal association seems to be related to the intrusion of the Minas granite. Metapelites, limestones, metapsammites and graphitic schists represent the host rock.

To the south and southeast of Minas town, quartz veins with gold-pyrite-hematite are a common feature. Jasperization - an iron-rich variety of amorphous silica slightly recristalized – is common there as well.

Regional exploration studies in the Fuente del Puma Formation were carried out by Zeegers and Spangenberg (1981) defining geochemical anomalies in stream sediments of Cu, Pb-Zn, Zn-As-Sb, Mo, Zn, Ba and Mn (Fig. 2).

Conclusions

The units that present mineralizations would display most probably ages around 700 Ma. The basement of the Lavalleja Group has probable age ca. 1.7 Ga. Mineralizations of Cu-Zn-Pb are related to basaltic sequences interbedded with sediments. The mineralizations include massive sulfides with pyrite- chalcopyrite-sphalerite-galena-pyrrotite-arsenopyrite- hematite. The bodies are small with lenticular shape and stockwork structures are frequent. The host rock usually shows hydrothermal alteration, with silicification, sericitization and chloritization. These mineralizations could represent deposits of Besshi Massive Sulphide Zn-Cu-Pb type described by Hõy (1995).

The bimodal nature of the volcanics, with mafics more abundant than felsics, and similar proportion of volcanics and sediments in the host rocks, suggest the studied mineralizations correspond to Besshi Type (Type 4 *sensu* Franklin et al., 1998).

The ore mineral associations with pyrrhotite ≥ pyrite and chalcopyrite, sphalerite and galena as main Cu, Zn and Pb sulfides may confirm this type of mineralizations according the criteria of Seal II et al. (2002). The chloritic alteration constitutes a distinctive feature of Precambrian volcanogenic deposits (Pirajno, 1992).

The Pb-Zn mineralizations associated to pelitics and calcareous (mainly dolostones) rocks could represent deposits of the sedimentary exhalative (SEDEX) Zn-Pb-Ag type described by MacIntyre (1995) and Leach et al. (1995), associated to a back-arc basin (*sensu* Sawkins, 1990). Similar mineralizations have been described in Canada (MacIntyre, 1991).

The mineralizations of the Fuente del Puma Formation are related to sedimentary succesions indicating depths less than 200 meters (presence of limestones and small amygdales in the volcanic rocks of the basin suggest shallow marine environment). The mineralizations of Kuroko type are related to depths in excess of 1000 meters (Ohomoto and Takabashi, 1983). The presence of barite and banded-iron formation (BIF) suggests a dysaerobic environment (Pirajno, 1992).

The general low Cu content suggests that the temperature of the system was lower than for most Kuroko deposits, as the hydrothermal fluid did not effectively transport this element. Considering a fluid temperature <300°C with salinity higher than normal seawater, the hydrostatic condition required for the formation of a Zn-rich and Cu-poor deposit might have been attained at a seawater depth <500 m.

The abundance of small abandoned mines in The Minas – Pan de Azúcar region indicates interesting potential for the regional exploration of massive sulfide deposits. Mineralizations seem to be related to submarine volcanism in a back-arc tectonic setting according to Sánchez-Bettucci et al. (2001).

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