GEOCHIMICA BRASILIENSIS 13(2): 099-108, 1999

CATHODOLUMINESCENCE OF QUARTZ AND THE EVOLUTION OF Pb AND Zn EPITHERMAL VEIN SYSTEMS IN THE LAGO FONTANA REGION, ARGENTINE PATAGONIA

C. Menezes[1]; A.P. Rolando[1]; L.A. Hartmann[1]; M.A.Z. Vasconcellos[1]; R. Etcheverry[2]

[1]Centro de Estudos em Petrologia e Geoquímica, Instituto de Geociências, UFRGS,
Av. Bento Gonçalves, 9500; CEP 91500-000, Porto Alegre, RS
[2]Instituto de Recursos Minerales, Universidad Nacional de La Plata, Calle 47 # 522; 1900 La Plata, Argentina

Recebido em 01/99; aprovado para publicação em 10/2000

ABSTRACT

Cathodoluminescence of quartz in the Lago Fontana epithermal Pb and Zn prospects and small deposits in the Patagonian Argentine indicates at least two generations of quartz. The first generation is volumetrically dominant and has low luminescence, while the second generation fills veinlets and is strongly luminescent. The deposition of galena, sphalerite and pyrite occurred simultaneously with the first generation of quartz and is the correct guide for the exploration of base metals in the region.

RESUMO

A catodoluminescência de quartzo nos prospectos e pequenos depósitos epitermais de Pb e Zn da região do Lago Fontana, Patagônia Argentina, indica a presença de duas gerações de quartzo, no mínimo. A primeira geração é volumetricamente dominante e possui baixa luminescência, ao passo que a segunda geração preenche vênulas e é fortemente luminescente. A deposição de galena, esfalerita e pirita ocorreu, simultaneamente, com a primeira geração de quartzo, sendo indicada como critério de prospecção de metais base na região.

INTRODUCTION

The Andean mountain chain has many prospects and small deposits of Pb and Zn in Argentine Patagonia, which have been targets for intense mineral exploration over the last decade in the search for major ore deposits. These epithermal systems contain many mineralized veins, which can be investigated by several techniques, including cathodoluminescence (CL) of quartz. This technique helps the identification of different generations of quartz and the relationship of these generations with the deposition of ore minerals. The purpose of this investigation is the determination of the quartz deposition sequence and associated ore minerals in the Lago Fontana region, Argentine Patagonia.

Cathodoluminescence is used in geology for the identification of minerals and microstructural characterization. Different generations of quartz are not usually distinguished in optical microscopy, but are commonly identified in cathodoluminescence studies by their different microstructures and luminescence (Seyedolali *et al.*, 1997). These cathodoluminescence studies of quartz are very useful for the understanding of sedimentation sources, for the pressure solution quantification in sedimentary rocks (Bruhn *et al.*, 1996; Marshal, 1988), for the metamorphic grade characterization in quartzites (Marshal, 1988) and for quartz deformation investigations in shear zones (Kanaory, 1986). The sequence of hydrothermal quartz deposition and related gold can be determined, whenever the cathodoluminescence studies are integrated with fluid inclusion studies (Boiron et al., 1992). Cathodoluminescence microscopy is thus an important technique for the understanding of geological processes, particularly those related to ore deposits.

GEOLOGY OF THE EPITHERMAL SYSTEMS

The vein system is located (Fig. 1) about 45 °S and 71 °30' W, close to the border of Argentina and Chile (Rolando *et al.*, 1999). Metamorphic rocks are mapped in the Patagonian Andes along the Pacific coast of southern Chile; ages vary from Upper Paleozoic to Triassic (Hervé *et al.*, 1998). In the Lago Fontana region, this metamorphic basement is not exposed and may be covered by the thick volcanosedimentary sequences of Upper Jurassic to Lower Cretaceous age (Haller & Lapido, 1982). The Patagonian Batholith is exposed 50 km to the west; several Cretaceous batholith aphophyses intrude the volcanic and sedimentary rocks in the region (Rolando *et al.*, 1999). Tertiary basalts and piroclastic rocks are minor (Dominguez, 1981). Large areas are covered by Quaternary glacial, fluvio-glacial, fluvial and aluvial deposits and basaltic lava flows (Ramos, 1981).

Two major vein systems were investigated – the Ferrocarrilera and the Cerro Bayo, located 12 km apart. The Ferrocarrilera vein system (Fig. 2) occurs in fractures in andesites, dacites and rhyolites of the Ñirehuao Formation. The main vein is oriented N 47 °E and typically has dips between vertical and 46 °W and its main ore minerals are sphalerite, galena and pyrite with associated gold. Several smaller veins are related to the main vein, in a complex branching system. This polimetalic deposit is about 850 m long and has maximum thickness about 1.3 m. Faulting caused sharp contacts between some veins and country rocks, but brecciation and silicification increased considerably the thickness of the altered rocks up to 6 m. The andesitic country rocks were altered and bleached, causing the formation of phyllic and propilitic alteration over few meters distance (Dominguez, 1981). The Cerro Bayo vein system occurs in Upper Jurassic and Cretaceous rocks of the Lago La Plata Formation, about 30 km distant, and its veins outcrop discontinuously for 150 m, with thickness less than 1 m, and they contain pyrite and galena. The veins occur in fractured ignimbrites, acid and intermediate tuffs and intercalated sedimentary rocks, all of which have been strongly altered by the epithermal process into illite, chlorite and minor kaolinite (Rolando *et al.*, 1999).

Isotopic age determinations (whole rock and mineral Rb/Sr; zircon U/Pb SHRIMP) show that both vein systems were formed at about 115 Ma, related to the major event of Victoria granite intrusion (Rolando *et al.*, 1999).

Based on fluid inclusion and stable isotope studies, the hydrothermal fluids that generated the ore in the Ferrocarrilera veins are of low salinity and evolved from meteoric waters (INREMI, 1998). The internal complex relationship in the quartz vein system needs further investigation to determine the sequence of quartz and ore minerals formation.

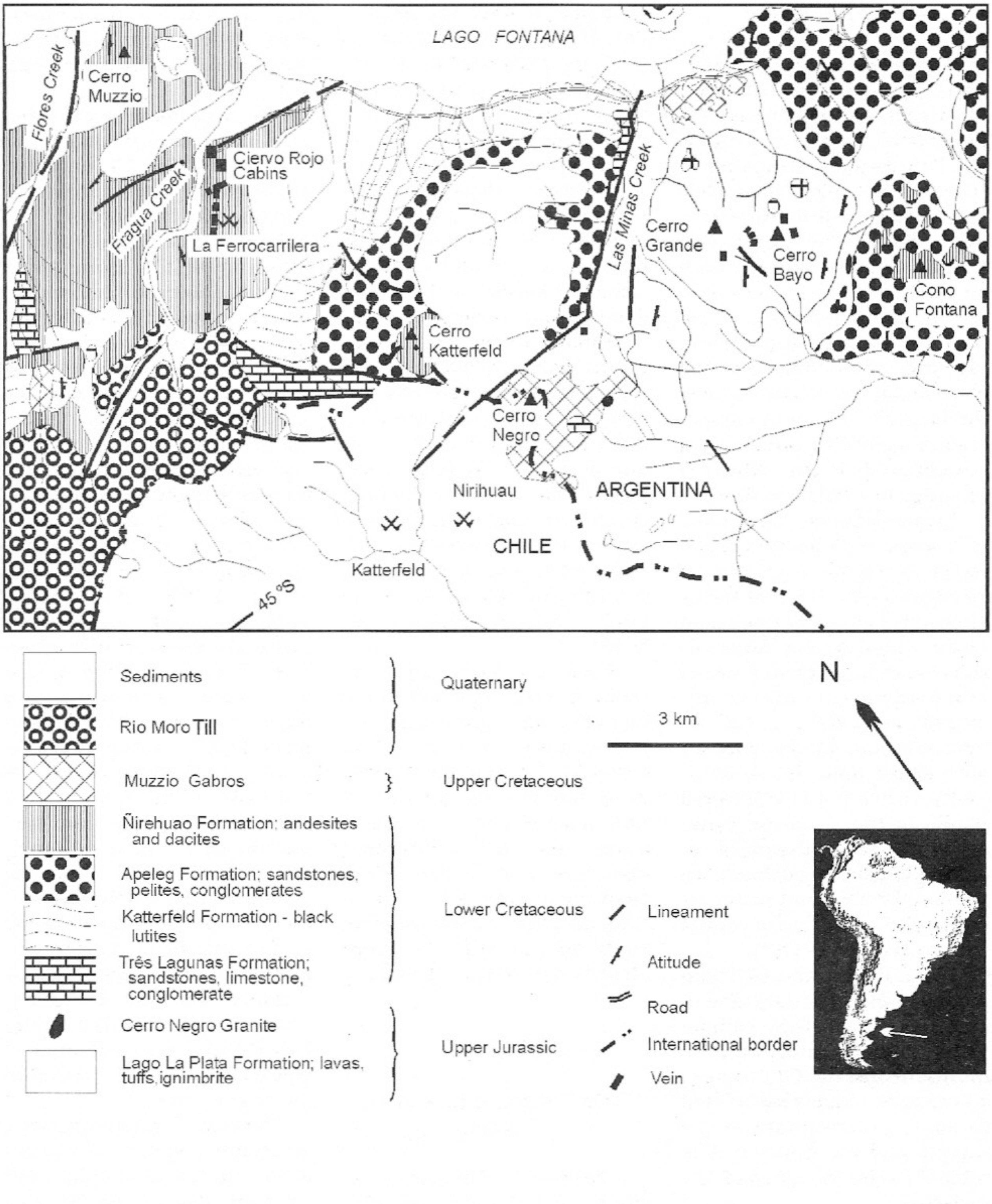

Figure 1 – Geological map of Lago Fontana region, showing two studied sites, Ferrocarrilera and Cerro Bayo. Inset shows location in South America.

METHODOLOGY

Cathodoluminescence microscopy was performed in a Cameca SX-50 electron microprobe at the Centro de Estudos em Petrologia e Geoquímica, Instituto de Geociências, Universidade Federal do Rio Grande do Sul, Porto Alegre, RS, Brazil. A photomultiplier with an S20R (blue sensitive) photocathode was attached in the port for optical microscopy viewing. The output from the photomultiplier is controlled by the same electronics as the secondary electrons, producing a scanning CL image, which is recorded in a Polaroid film.

In this technique, the sample is exposed to an electron beam, which causes the excitation of electrons in the external layers of unstable atoms or ionization of this atom. A later decay results in the emission of photons in a wide range of the electromagnetic spectrum. In CL, attention is addressed to photons with wavelengths in the ultraviolet, visible and near infra-red region of the electromagnetic spectrum. The emission of radiation is usually attributed to structural defects or to trace element inclusions in the crystal lattice (Marshall, 1988).

The combination of beam scanning and light detection in a selected area of the sample allows the formation of a monochromatic CL image, where each pixel is associated to an x, y coordinate in the sample and the grey level is related to the intensity of CL emission.

In this work, CL images were used as a support to evaluate the genesis and evolution of the materials investigated. This kind of image does not allow by itself the identification of the mechanisms responsible for the CL emission, such as defects in the structure or presence of impurities (Seyedolali *et al.*, 1997). The identification of these mechanisms is much more complex and requires several complementary techniques.

CL images show the microstructure of the sample and support the interpretation of the genesis and evolution of the studied materials. In this investigation, microphotography was also made in the same areas imaged by CL, to integrate with the interpretation of the CL microstructure. The characterization of the activators of CL in quartz is still far from completed. This is due to the high quartz purity and to the fact that, apart from incorporation of trace elements, quartz CL is strongly influenced by structural defects (Seyedolali *et al.,* 1997).

Several quartz and ore samples were collected in the Lago Fontana region, thin sectioned, polished and carbon coated for CL imaging. Images were recorded on a Polaroid 55 film, scanned and composed in a computer. All minerals mentioned were identified in the electron microprobe with an EDS detector, except jarosite, kaolinite and illite that were identified by X-ray diffraction.

RESULTS

The Ferrocarrilera Vein System

The quartz veins in this system are zoned – cores of veins are enriched in pyrite, rims of veins in galena and sphalerite, and both zones were sampled (Fig. 3). Quartz is drusiform and crustiform, and seems to have been partly recrystallized under the microscope. The CL images show two main quartz microstructures, interpreted as two different generations (Figs. 4, 5 and 6).

The first main microstructural generation of quartz has low intensity of CL emission and is rather heterogeneous. It shows intercalations of coloform quartz and variable intensity of CL along some growth planes of individual quartz crystals (Fig. 4b, bright/dark bands in lower left portion). These heterogeneous zones could be interpreted as a third generation of quartz, but we postulate, after careful observation of many images, that they formed during the deposition of phase 1, as a result of growth in oscillating physicochemical conditions (Nillni & Stöckhert, 1996). Quartz of this generation also present grey planar and irregular microstructures (Fig. 5), that are similar to those described by Seyedolaly *et al.* (1997) in deformed quartz crystals. Because of this similarity, some of the features observed in the Ferrocarrilera quartz are also interpreted as due to deformation. The observation that the galena and sphalerite crystallized simultaneously with the first generation of quartz is important for metallogenic interpretations and mineral exploration in the Lago Fontana region. It is also the most voluminous phase of quartz precipitated in this vein system.

The second and less abundant generation of quartz is homogeneous and strongly luminescent and formed after brecciation of the first generation of quartz. The fluids interacted with quartz of the first generation, sealing open fractures and spaces in pressure shadows around sulphides and also filling many small veinlets (Figs. 4, 5 and 6).

These features indicate shallow conditions for the emplacement of the quartz. The grain size of quartz seems to control some of the replacement by the new generation; the larger crystals of the first generation are mostly cut by the new veinlets, while the smaller crystals tend to be entirely replaced (Fig. 5). No evidence was encountered for co-precipitation of this quartz and ore. The cause of different light emission of quartz under electron bombardment may be related either to different fluid compositions or to different types and proportions of defects.

Figure 2 – Photographs of two studied veins; a – Ferrocarrilera, b – Cerro Bayo. Arrow indicates hammer for scale.

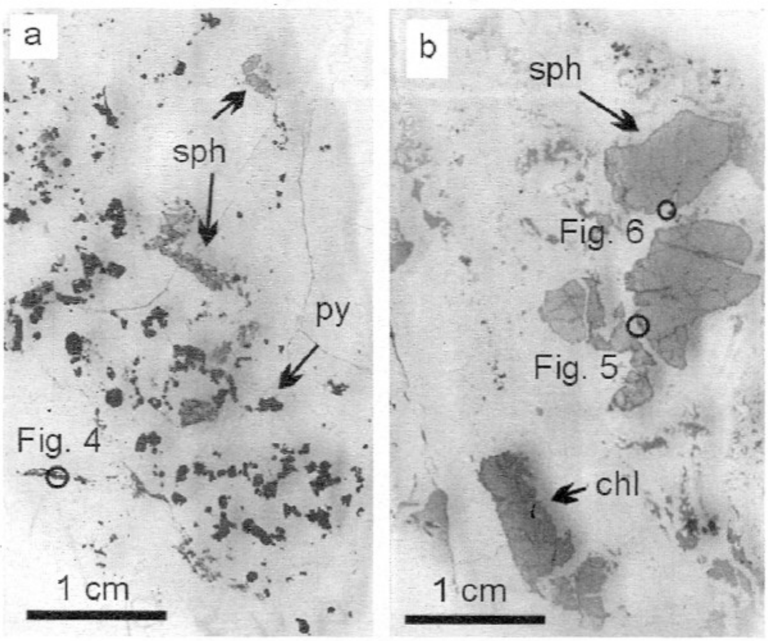

Figure 3 – Scanned thin sections of Ferrocarrilera mineralized vein. Location of Figs. 4, 5 and 6 indicated. Quartz is clear and volumetrically dominant in the two thin section and in the vein; sph = sphalerite, py = pyrite, chl = chlorite.

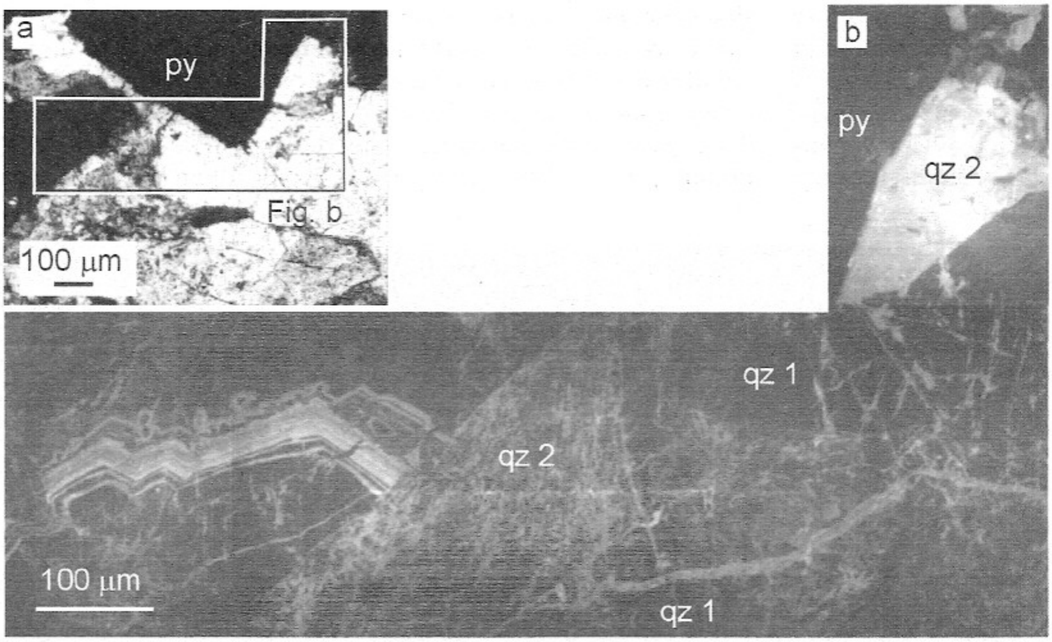

Figure 4 – Microphotograph (a) and composite of six cathodoluminescence images (b) of Ferrocarrilera vein. Quartz is clear in a; py = pyrite, qz = quartz. In b, two generations of quartz indicated as qz 1 = dark in CL image and qz 2 = bright veinlets and portions. Thinly banded bright/dark quartz on lower left is probably qz 1.

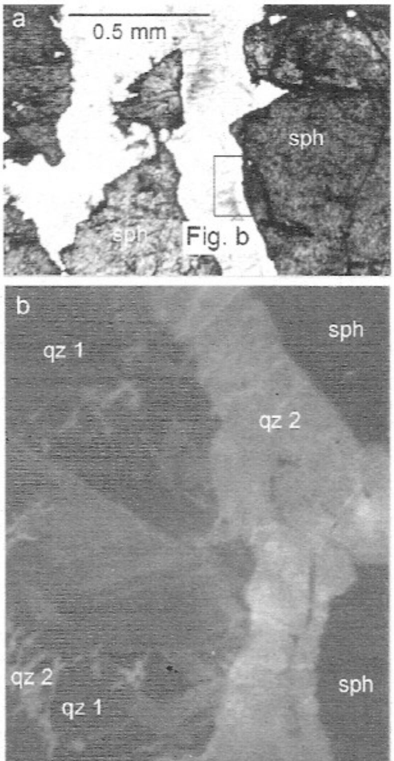

Figure 5 – Microphotograph (a) and cathodoluminescence image (b) of Ferrocarrilera vein. Quartz is clear in a; sph = sphalerite. In b, two generations of quartz indicated as qz 1 = dark in CL image and qz 2 = bright veinlets and 100 μm thick vein formed in pressure shadow of sphalerite crystal.

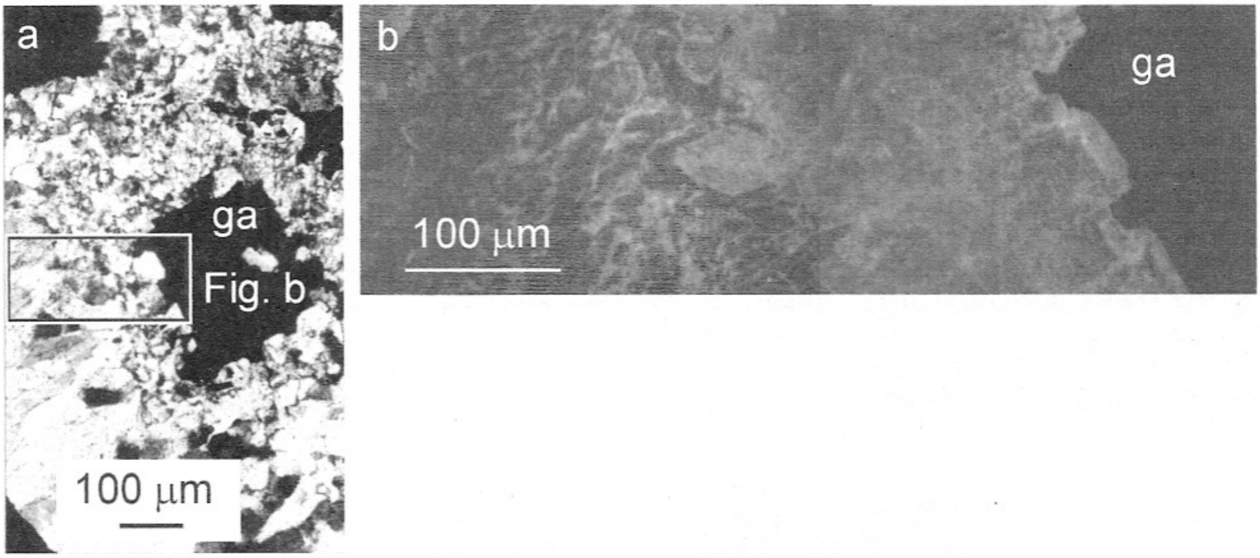

Figure 6 – Microphotograph (a) and composite of three cathodoluminescence images (b) of Ferrocarrilera vein. Only galena (ga) and quartz (dominantly bright in CL) in a. Quartz vein occupies 10-20 μm pressure shadow near galena crystal in b; fine grained quartz dominates volume around galena crystal; larger quartz crystals occur farther away.

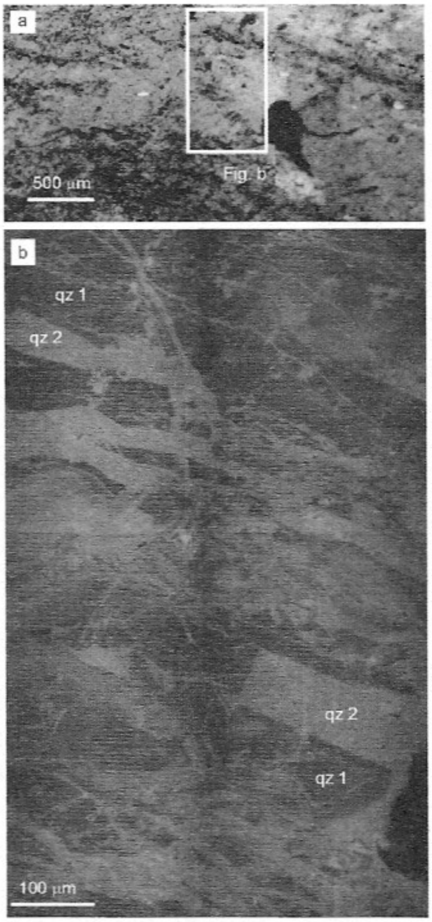

Figure 7 – Microphotograph (a) and composite of ten cathodoluminescence images (b) of Cerro Bayo vein. Quartz dominates the vein; in a, black hole 0.5 mm is seen. In b, CL image shows a region of the vein dominated by the second generation of bright quartz (qz 2) as veinlets in dark qz 1. Dark shadow that runs vertical in center of Figure b is an artifact.

The Cerro Bayo Vein System

In the Cerro Bayo vein system, quartz is associated with pyrite, chalcopyrite and galena and some jarosite partly covers the crystals. Similar to the Ferrocarrilera vein system, quartz shows microstructures such as drusiform, crustiform and coloform and it seems to be partly recrystallized. Quartz is fractured and nearly always sealed by drusiform quartz veinlets (Figs. 7 and 8a). As seen on the CL images, quartz associated with the ore minerals has low intensity of CL emission, and it is cut by a second generation of quartz along highly luminescent veinlets (Fig. 7). Some recrystallization is also observed, but has little effect on the original CL pattern of the quartz.

The most voluminous quartz generation (qz 1) also occurs as alternating bright and dark bands (Fig. 8) and some have intermediate luminescence. This suggests that the intercalations may have formed by variations in the conditions of fluid migration and composition. It may be one event of quartz deposition, similar to Ferro Carrillera vein.

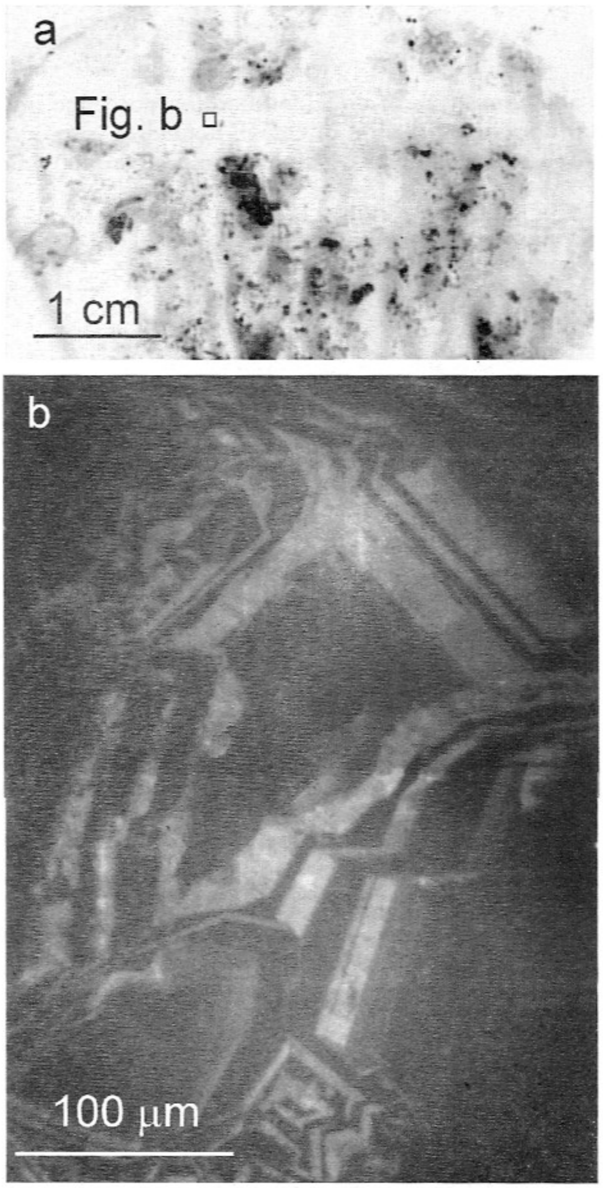

Figure 8 – Scanned thin section (a) and composite of two cathodoluminescence images (b) of Cerro Bayo vein. In a, quartz dominates volumetrically the vein; darker patches are oxides and alteration products. In b, quartz is either dark or bright, but is interpreted as formed with the first generation of quartz.

CONCLUSIONS

Two generations of quartz were identified in the mineralized zones of the Ferrocarrilera and the Cerro Bayo, both very similar. The first generation is volumetrically dominant and composed of low luminescent quartz with drusiform and coloform microstructures, formed simultaneously with the deposition of Pb and Zn ore minerals (galena, sphalerite, pyrite), whereas second generation is highly luminescent, not abundant and was deposited in veinlets and pressure shadows and replaced the first generation, wherever the quartz was fine grained. The deposition of galena, sphalerite and pyrite simultaneously with the first generation of quartz is the correct guide for the exploration of base metals in the region.

ACKNOWLEDGEMENTS

The authors wish to thank Ricardo Etcheverry and Mabel Lanfranchini for their help during field work, to Cintia Matsumura for her engagement and orientation in the Electron Microprobe Laboratory (UFRGS) and to Professor David Groves and Prof. Dr. Evandro Fernandes de Lima for their invaluable support. The cathodoluminescence apparatus was installed at UFRGS with financial support from the PADCT project "Caracterização de minérios e rejeitos de mineração brasileiros", coordinated by Dr. Onildo Marini. Fundação de Amparo à Pesquisa do Estado do Rio Grande do Sul offered an undergraduate scholarship ("Iniciação Científica") to the first author. Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) is acknowledged for financial support.

REFERENCES

BOIRON, M.C.; ESSARRAJ, S.; SELLIER, E.; CATHELINEAU, M.; LESPINASSE, M.; POTY, B. (1992) Identification of fluid inclusions in relation to their host microstructural domains in quartz by cathodoluminescence. Geoch. Cosmoch. Acta, **56**:175-185.

BRUHN, F.; BRUCKSCHEN, P.; MEIJER, J.; STEPHAN, A.; RICHTER, D.K.; VEIZER, J. (1996) Cathodoluminescence investigations and trace elements analysis of quartz by micro-pixe: implications for diagenetic and provenance studies in sandstone. Can. Min., **34**:1223-1232.

DOMINGUEZ, E.A. (1981) Genesis y geoquimica de la mineralizacion de los yacimientos "Los Manatiales" y "Lago Fontana", provincia del Chubut. Rev. Assoc. Geol. Argentina, **36**(2):123-142.

HALLER, M. & LAPIDO, R. (1982) The Jurassic-Cretaceous volcanism in the Septentrional Patagonian Andes. Earth-Sci. Rev., **18**:395-410.

HERVÉ, F.; AGUIRRE, L.; GODOY, E.; MASSONE, H., MORATA, D.; PANKHURST, R.; RAMIREZ, E.; SEPÚLVEDA, V.; WILLNER, A. (1998) Nuevos antecedentes acerca de la edad y las condiciones de P-T de los Complejos Metamórficos en Aysen, Chile. *In:* Congresso Latino-Americano de Geologia, **1**, Buenos Aires. Assoc. Argentina Geol., Anais, **2**:134-137.

INREMI (1998) Investigacion geológica minera orientada a la localización y exploración de metales nobles y otros recursos minerales en el Macizo del Deseado, Santa Cruz. Report to Agencia Nacional de Promoción Científica y Tecnológica de Argentina, v. **I, II** (unp.).

KANAORY, Y. (1986) A SEM cathodoluminescence study of quartz in mildly deformed granite from the region of the Atotsugawa fault, central Japan. Tectonophysics, **131**:131-146.

MARSHALL, D.J. (1988) Cathodoluminescence of geological materials. Unwin Hyman, Boston, Massachussets, 146 p.

NILLNI, A.M. & STÖCKHERT, B. (1996) Catodoluminescencia y microtermometria en cuarzo hidrotermal. Yacimiento Cerro Vanguardia. Pcia. De Santa Cruz, Argentina. In: Congresso Geológico Argentino, 13, y Congresso de Exploración de Hidrocarburos, 3, Comodoro Rivadavia. Actas, **3**:181-188.

RAMOS, V. (1981) Descriptión geológica de la Hoja 47 a b "Lago Fontana", Provincia del Chubut, Argentina. Serv. Geol. Nac., Boletin **183**, 143p.

ROLANDO, A.P.; HARTMANN, L.A.; MACAMBIRA, M.B.; ORESTES, J.O.S.; FERNANDEZ, R.; ETCHEVERRY, R.; SCHALAMUK, I.A.; McNAUGHTON, N.J. (1999) Isotopic contraints on the Pb, Zn, Ag, Cu, Au metallogeny and Andean crustal evolution in the Lago Fontana Region, Patagonia. In: South American Symposium on Isotope Geology, 2, Ciudad de Villa Carlos Paz, Argentina. Actas, p.491-494.

SEYEDOLALI, A.; KRINSLEY, D.H.; BOGGS, S. Jr.; O'HARA, P.F.; DYPVIK, H.; GOLES, G.G. (1997) Provenance interpretation of quartz by scanning electron microscope-cathodoluminescence fabric analysis. Geology, **25**(9):787-790.