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# EPITHERMAL PRECIOUS METAL DEPOSITS HOSTED IN THE CERROS BRAVOS VOLCANIC COMPLEX, MARICUNGA BELT, CHILE: A REVIEW

# DEPOSITOS EPITERMALES DE METALES PRECIOSOS HOSPEDADOS EN EL COMPLEJO VOLCANICO CERROS BRAVOS, FRANJA MARICUNGA, CHILE: UNA REVISION

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## RESUMEN

*La mineralización epitermal de metales preciosos en el complejo volcánico Cerros Bravos fue producto de un evento único, localizado en los bordes del complejo volcánico. La información estudiada indica que la actividad hidrotermal y la mineralización ocurrieron en un ambiente de tipo caldera, asociado directamente al volcanismo y magmatismo de Cerros Bravos, el cual, a su vez, está ligado a estructuras regionales de gran extensión.*

*El desarrollo de la caldera tuvo lugar entre el Oligoceno Superior (25 Ma) y el Mioceno Inferior (15 Ma). Durante el Mioceno Medio, se dio lugar a intenso volcanismo resurgente, consistente en estratovolcanes dacíticos a andesíticos.*

## ABSTRACT

*Precious metal epithermal mineralization in the Cerros Bravos Volcanic Complex ocurred as a single event, concentrated at the margins of the volcanic complex. Information indicates that hydrothermal activity and mineralization took place in a caldera environment, associated directly to magmatism and volcanism of Cerros Bravos, in turn, related to major regional structures.*

*Caldera development took place between upper Oligocene (25 Ma) and middle Miocene (15 Ma), while mineralization ocurred until lower Miocene. Intense resurgent volcanism consisting of dacitic to andesitic stratovolcanoes took place in the middle Miocene.*

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## INTRODUCTION

During the last decade, various epithermal precious metal deposits have been discovered in the Cerros Bravos Volcanic Complex, located in the III Region, Chile (Fig. 1).

All of the deposits and prospects discovered to date are similar in their geological characteristics and are apparently related. Various of these deposits have previously been described, such as Esperanza (Vila, 1991; Moscoso et al, 1992), La Coipa (Oviedo et al., 1991) and Can Can (Cecioni & Dick, 1992; Townley, 1992). The regional geology of the area, the linear trend of precious metal deposits now commonly referred to as the Maricunga Belt, has been described by various authors, among them, Aguilar (1984), Davidson & Mpodozis (1991), Moscoso et al. (1992; 1993), and Sillitoe et al. (1991).

These descriptions, however, do not attempt to explain the deposition of precious

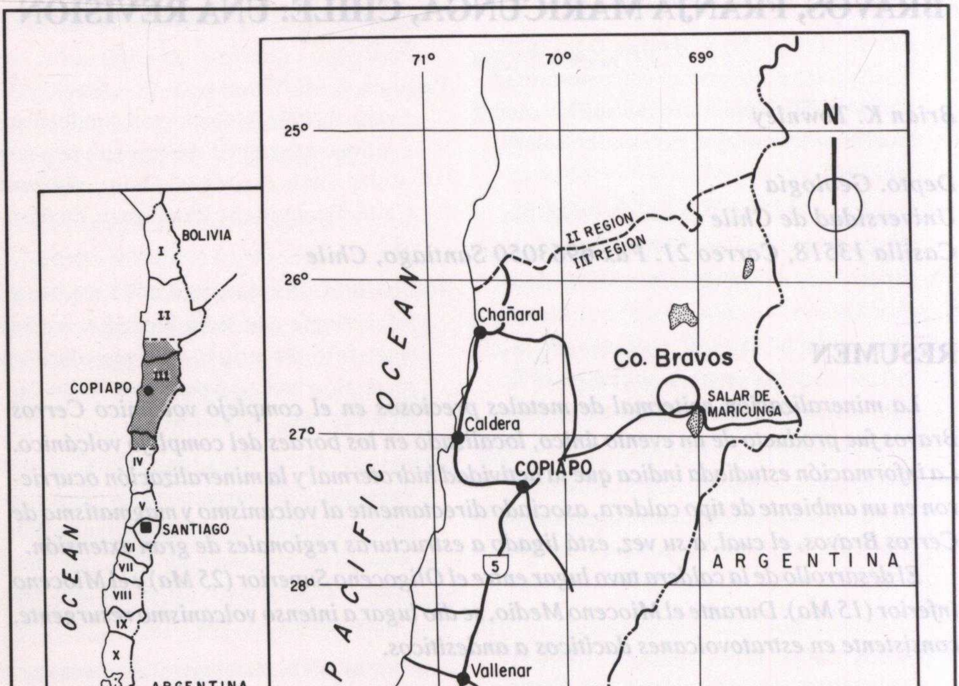


*Fig. 1.- Mapa de ubicación.*
*Fig. 1.- Location map ubication.*

metal mineralization in terms of the magmatic and tectonic history of the hosting Cerros Bravos Complex. Thus, the objetives of this paper are to compare known ore deposits and prospects in the area, and relate them to regional structures and magmatism.

## GEOLOGICAL SETTING

Rock formations in the area of Cerros Bravos range from Paleozoic to Recent (Fig. 2). The oldest rocks outcropping in the area are sandstones, shales and mudstones of the Chinches Formation, of Devonian to Carboniferous age (Mercado, 1982). They are overlain by dacitic to andesitic flows of the Pantanoso Formation, of Permo-Triassic age (Mercado, 1982).

The above formations are overlain by arkosic sandstones and carbonaceous black shales of the La Ternera Formation, of late Triassic age (Brüggen, 1950), marine limestones and andesitic volcanic rocks of the Lautaro Formation, of Jurassic age (Segerstrom, 1968), red sandstones of the Quebrada Monardes Formation, of Late Jurassic to Early Cretaceous age (Mercado, 1982), and volcaniclastic rocks of the Quebrada Seca formation, of late Cretaceous age (Mercado, 1982).

Cenozoic rocks consist of an assemblage of volcanic rocks (aproximately 1000 to 1600 meters thick) that form a NNE-SSW trending volcanic cordillera which developed during Late Oligocene to early Miocene time, comprising the Cerros Bravos volcanic complex. These volcanic rocks are mainly dacitic to andesitic in composition and include, from oldest to youngest, ignimbrites dated at 25 Ma (Moscoso et al., 1992; 1993), red and green andesites and breccias, green and grey tuffs, breccias and yellow-brown tuffs, ignimbrites, ash flows, block and ash flows of dacitic composition, and finally dacitic to andesitic lavas associated with stratovolcanoes, dated at 15 Ma (Oviedo et al., 1991 ).

The youngest rocks in the sequence are Late Miocene gravels and interbedded ignimbrites belonging to the San Andres formation (Clark et al., 1967).

Intrusive rocks consist of Paleozoic granitoids that occur mainly in the northern and southern parts of the area, and Paleocene to Eocene NS-trending tonalitic porphyries which outcrop in a discontinous belt, mainly along the western part of the area (Fig. 2). Late Oligocene to Early Miocene subvolcanic rocks are abundant, consisting of dacitic to rhyolitic domes and plugs that tend to border the Cerros Bravos volcanic complex (Fig. 2).These have been dated by Moscoso et al. (1992; 1993) and Sillitoe et al. (1991) between 25 and 15 Ma.

The main structural features of the area are NNE-SSW and NS horst and graben systems bordered by regional reverse faults. These faults are covered by late volcanic activity of the mid Miocene Cerros Bravos volcanic complex. Other significant structural systems trend NNW-SSE and less commonly EW and NNE-SSW, typically being normal faults which affect the Cerros Bravos volcanic complex (Fig. 2).

## EPITHERMAL PRECIOUS METAL MINERALIZATION

Precious metals mineralization is a common feature in the Cerros Bravos volcanic complex, where all known deposits and prospects generally occur along its periphery. These deposits include Esperanza, La Coipa, Can Can, Coipa Norte, along with prospects of varying degrees of potential. The latter include Brecha Norte,

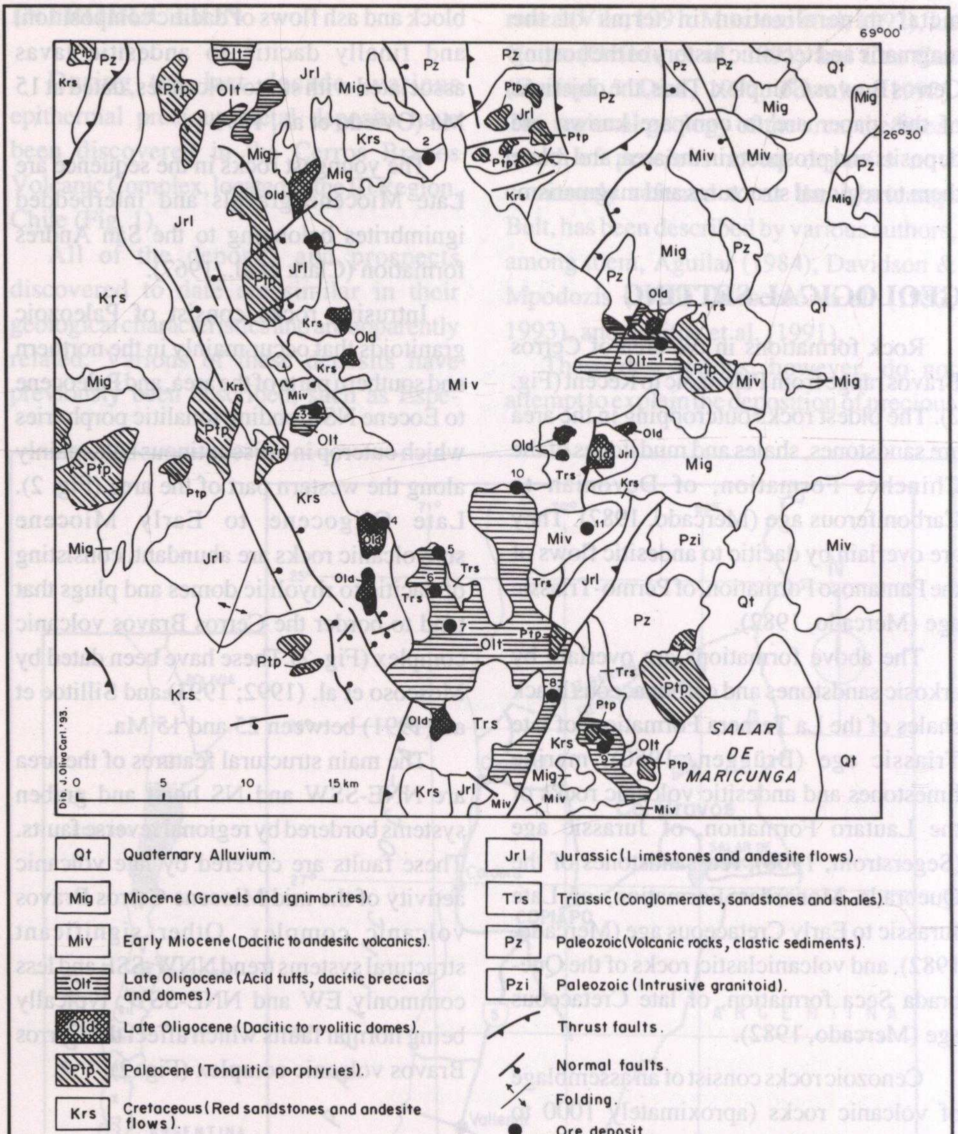


*Fig. 2.- Regional geologic setting of the Cerros Bravos volcanic complex. Known ore deposits or projects appear at borders of the volcanic complex, being: 1) Esperanza, 2) Tinajas, 3) Indagua. 4) Vicuñita, 5) Coipa Norte, 6) Can Can, 7) Coipa, 8) Torito N, 9) Torito SE, 10) Consuelo, and 11) Codocedo (Map Modified from Oviedo et al., 1991; Aguilar, 1984; Moscoso, et al., 1992;1993; Vila, 1991; Davidson & Mpodozis, 1991; Sillitoe et al.. 1991).*

*Fig. 2.- Marco geológico regional del complejo volcánico Cerros Bravos. Depósitos y proyectos conocidos aparecen localizados en los bordes del complejo volcánico. siendo: 1) Esperanza, 2) Tinajas, 3) Indagua, 4) Vicuñita, 5) Coipa Norte, 6) Can Can, 7) Coipa, 8) Torito, 9) Torito SE, 10) Consuelo, y 11) Codocedo (Mapa modificado de Oviedo et al., 1991; Aguilar, 1984; Moscoso et al., 1992; 1993; Vila, 1991; Davidson y Mpodozis, 1991; Sillitoe et al., 1991).*

Torito N, Torito SE, Codocedo, Tinajas, Indagua and Vicuñita (Fig. 2).

The deposits have very similar characteristics, described below. Characteristics of Coipa, Can Can and Esperanza are summarized in Table 1.

## ESPERANZA

Description of the Esperanza precious metal deposit is based on work by Vila (1991) and Moscoso et al. (1992; 1993).

The Esperanza deposit is located at the north-eastern border of the Cerros Bravos volcanic complex (Fig. 2). It exhibits strong structural control, mainly NNE and lesser NNW. It is hosted by black shales and sandstones of Triassic age (La Ternera formation) and by dacitic tuffs and dacitic porphyry flows and domes of Late Oligocene and early Miocene age (23 Ma). The system is overlain by non-altered, middle Miocene andesitic flows (Fig. 3).

Hydrothermal alteration at Esperanza consists of strong silification, advanced argillic and quartz-alunite alteration, together with the deposition of gypsum, barite, quartz, siderite and Fe oxides, limited mainly to structures. Ore mineralization consists of a widespread blanket-like body with silver, underlain by structurally-controlled, vein-like bodies carrying gold, lesser amounts of silver, along with anomalous As, Bi, Pb and Sb. Hg is also anomalous and more widespread. The presence of a silica cap, silica sinters and Hg anomalies suggest that the system was emplaced at, or very close to the paleosurface.

The hydrothermal system at Esperanza developed in an area of volcanic collapse (aproximately 3,5 X 3,5 Km) controlled by NW and NS structures, where hydrothermal alteration was localized by intrusive domes which were emplaced near the borders of the collapsed area. Pyroclastic ash flows dated at 25 Ma are possibly genetically related to the collapse episode between Cerro Amarillo and Arqueros. Hydrothermal activity, mineralization and volcanism at Esperanza is considered to have occured as a single contemporaneous event.

## CAN CAN

The following description of the Can Can precious metal ore deposit is based on work by Cecioni and Dick (1992), Townley (1991; 1992).

The Can Can ore body is located at the southern border of the Cerros Bravos volcanic complex (Fig. 2). It shows strong structural control, mainly NNE and NNW. The exposed area is uplifted and exposed by a horst system. The deposit is hosted by black shales and sandstones of Triassic age (La Ternera formation) and unconformably overlying dacitic tuffs and flows of late Oligocene to early Miocene age. The above assemblage is in turn overlain by fine felsic tuffs which are altered only at their base (Fig. 4).

Hydrothermal alteration at Can Can consists of strongly silicified structures associated with advanced argillic and abundant quartz-alunite alteration, together with gypsum, barite, jasper, and Fe oxides. Ore mineralization consists of a cone-shaped body containing predominantly silver, underlain by structurally-controlled bodies containing gold and silver.

Presence of geyserites, silica cap and open fractures filled by silicified gravels, indicate that the system developed near the paleosurface.

Fluid inclusion studies at Can Can gave homogenization temperatures of between 160 and 350°C, divided in two groups, one

# TABLE 1: GENERAL DESCRIPTION OF MAIN ORE DEPOSITS/PROSPECTS IN THE CERROS BRAVOS VOLCANIC COMPLEX

## TABLA 1: DESCRIPCION GENERAL DE LOS PRINCIPALES DEPOSITOS/PROSPECTOS EN EL COMPLEJO VOLCANICO CERROS BRAVOS.

| Deposit or Prospect | Reserves an Grades (M.t.) M | Host Rock | Hidrothermal Alteration | Hipogene Mineralization | Age of Mineralization (Ma) | References |
|---|---|---|---|---|---|---|
| Esperanza | 4 million<br>1 ppm Au<br>300 ppm Ag | Triassic black shales and Miocene dacitic flows and domes. | Silification, advanced argillic, quartz-alunite. | Pyrite, gold, arsenopyrite sphalerite, galena, native Ag, enargite, argentite. | 23 - 23 | 1; 2; 3. |
| La Coipa | 78 million<br>1.2 ppm Au<br>76 ppm Ag | Triassic black shales and Miocene dacitic flows and domes. | Silification, advanced argilic, quartz-alunite. | Pyrite, gold, chalcopyrite, sphalerite, galena, native Ag, tetrahederite, enargite, electrum, bornite, covellite. | 20 - 23 | 2; 3; 4; 5; 6; 7; 8; 9. |
| Can Can | 1 million<br>12 ppm Au<br>70 ppm Ag | Triassic black shales and Miocene dacitic flows and domes. | Silification, advanced argillic, quartz-alunite. | Gold, silver, electrum chalcosite, chalcopyrite. | 18 | 2; 10; 11; 12; 13. |

M (M.T.)= metric tons.

Key to reference: 1) Vila, 1991; 2) Colley et al., 1989; 3) Moscoso et al., 1992, 1993; 4) Oviedo et al., 1991; 5) Bema, 1991; 6) Camus, 1990; 7) Lenis, 1989; 8) Rivera, 1988; 9) Zentilli, 1974; 10) Dick et al., 1990; 11) Dick, pers. commun. 1990; 12) Freeze, 1990; 13) Townley, 1992.

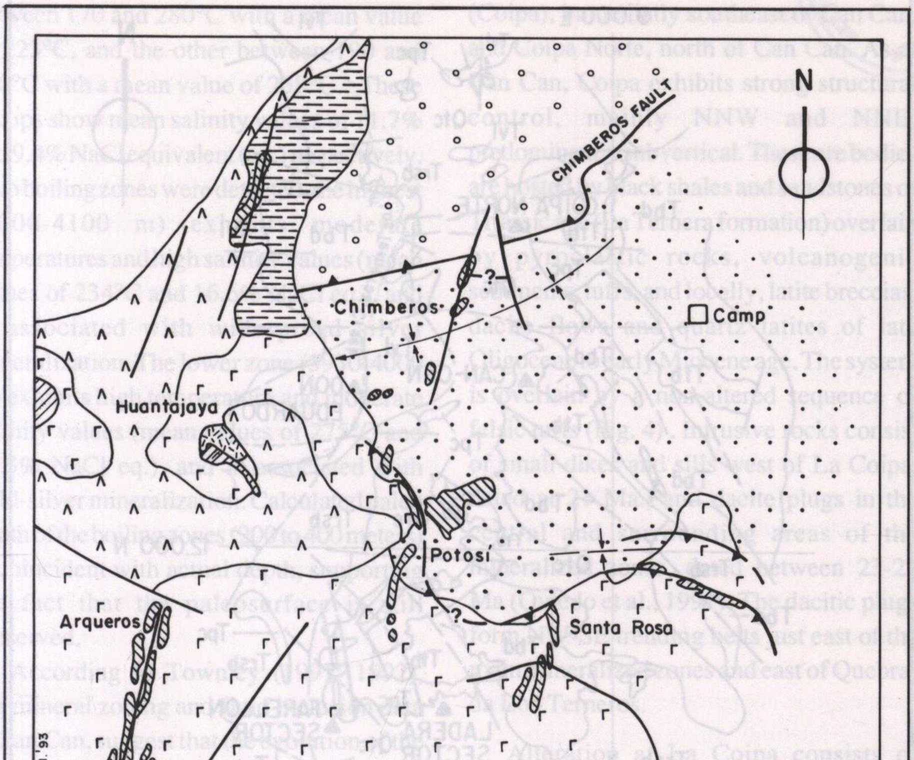


*Fig. 3.- Geological map of the Esperanza project (after Vila, 1991).*

*Fig. 3.- Mapa Geológico del proyecto Esperanza (basado enVila, 1991).*

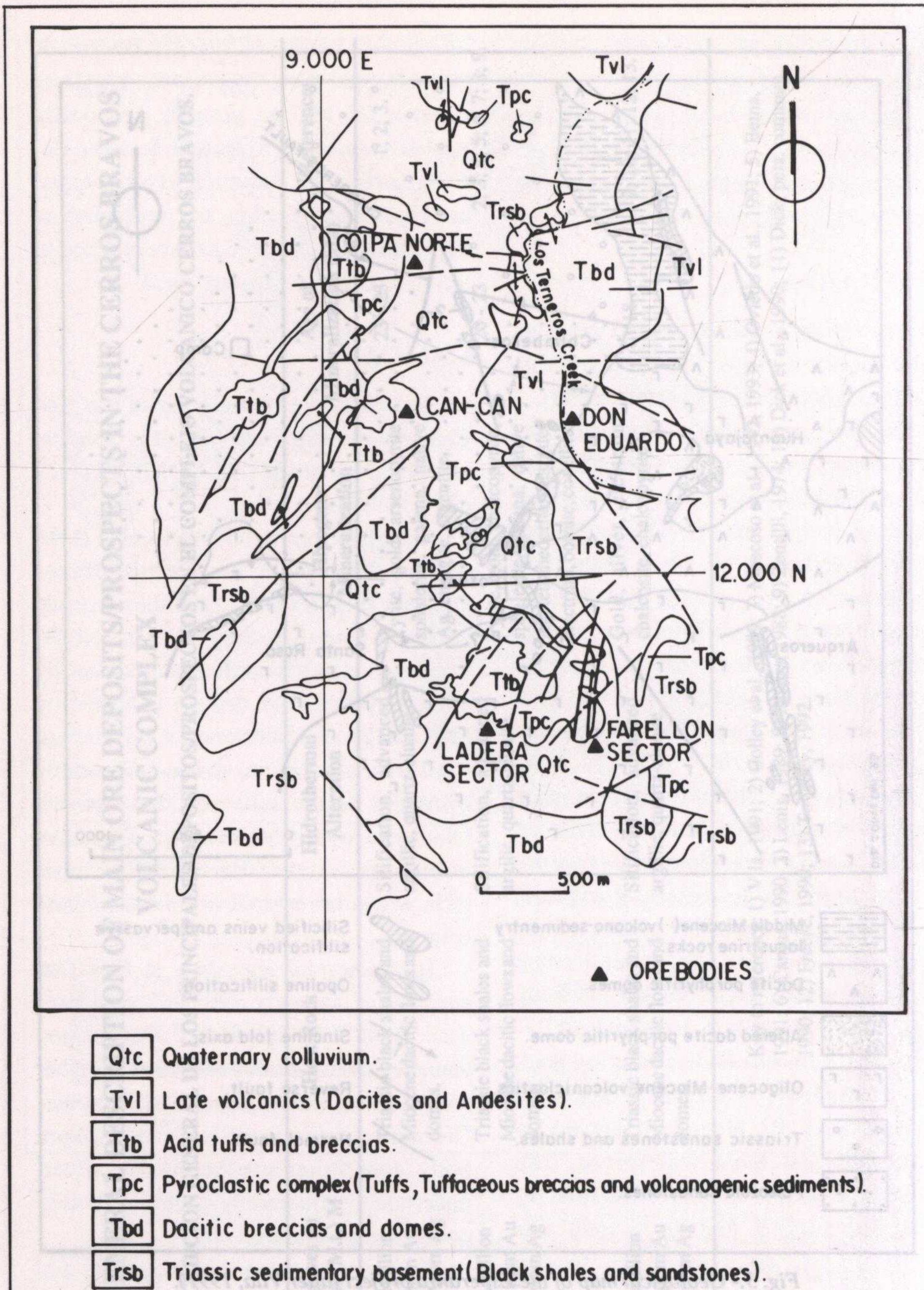


*Fig. 4.- Geological map of La Coipa district (Modified from Oviedo et al., 1991 and Dick et al., 1990).*

*Fig. 4.- Mapa geológico del distrito La Coipa (Modificado de Oviedo et al., 1991 y Dick et al., 1990).*

between 170 and 280°C with a mean value of 223°C, and the other between 190 and 350°C with a mean value of 258°C. These groups show mean salinity values of 11.7% and 9.4% NaCl equivalent (eq.) respectively. Two boiling zones were detected, the highest (4000-4100 m) exhibits moderate temperatures and high salinity values (mean values of 234°C and 16,6% NaCl eq.), and is associated with widespread silver mineralization. The lower zone (3930-4000 m) exhibits high temperature and moderate salinity values (mean values of 275°C and 10,3% NaCl eq.), and is associated with gold-silver mineralization. Calculated paleo depth of the boiling zones (200 to 400 meters) is coincident with actual depth, supporting the fact that the paleosurface is still preserved.

According to Townley (1991; 1992), ore mineral zoning and fluid inclusion data at Can Can, suggest that the evolution of the system ocurred in two stages. The initial stage, was associated with high salinity, predominantly silver-bearing fluids, which was succeded by a second-stage, deeper event, highly structurally - controlled. These later fluids, lower in salinities, were rich in gold and silver. Hydrothermal activity, mineralization and volcanism at Can Can ocurred practically as a single contemporaneous event .

## LA COIPA

The following description of the La Coipa precious metal ore deposit is based on work by Oviedo et al. (1991) and Swaneck (1992).

La Coipa is located at the southern border of the Cerros Bravos volcanic complex, neighbouring Can Can (Fig. 2). It consists of three main ore bodies, Ladera and Farellón (Coipa), immediatly southeast of Can Can, and Coipa Norte, north of Can Can. As at Can Can, Coipa exhibits strong structural control, mainly NNW and NNE, predominantly subvertical. These ore bodies are hosted by black shales and sandstones of Triassic age (La Ternera formation) overlain by pyroclastic rocks, volcanogenic sediments, tuffs, and locally, latite breccias, dacite flows and quartz latites of late Oligocene to early Miocene age. The system is overlain by a non-altered sequence of felsic tuffs (Fig. 4) . Intrusive rocks consist of small dikes and sills west of La Coipa, dated at 21 Ma., and dacite plugs in the central and surrounding areas of the mineralized zones, dated between 23-22 Ma (Oviedo et al., 1991). The dacitic plugs form NW-SE trending belts just east of the main mineralized zones and east of Quebrada Los Terneros.

Alteration at La Coipa consists of strongly silicified structures and pervasive advanced argillic alteration. Vuggy silica textures and alunite are a common feature of alteration, together with hematite, limonite, goethite, jarosite, gypsum and barite. Mineralization consists of silver, which is abundant in higher parts of the system, associated with strong supergene enrichment. Gold appears in native form, limited mainly to structures, and was deposited deeper below the silver, preferentially in the Triassic sedimentary unit.

K-Ar dating of rocks at La Coipa (Oviedo et al., 1991) show that the volcanic field which hosts mineralization was active between aproximately 25 Ma (Late Oligocene) and 20 Ma (early Miocene). Late volcanic activity, unaltered and unmineralized, was dated between 20 and 14 Ma (Oviedo et al., 1991). Dating of mineralization indicates a maximum age between 23 and 22 Ma. Thus, volcanic and subvolcanic activity are practically contemporaneous to mineralization.

## OTHER PROJECTS

Only limited information is available from other, less important prospects in the Cerros Bravos area. Most of the information which follows is based on field observations by the author .

Torito Norte: This prospect exhibits widespread hydrothermal alteration and local indications of epithermal mineralization. The alteration is hosted by late Oligocene-early Miocene volcanic rocks, including volcanosedimentary deposits, pyroclastic and volcanoclastic rocks of dacitic composition. Numerous dacitic domes control ring fractures which host alteration and mineralization. Structural control of alteration is evident, mainly NNE and NNW. Various structures exhibit strong silification and associated intense acid leaching alteration. Native sulphur deposits are locally present in pockets within the volcanic rocks. Massive silica replacement locally occurs at surface. Precious metals mineralization, where present, is limited to thin structures.

Torito SE: This zone is very similar in characteristics to Torito Norte, although field observations and petrography indicate that the exposed area corresponds to a lower level of erosion, most probably the result of block faulting and uplift.

Codocedo: This area is characterized by dacitic volcaniclastic rocks, and exhibits strong silification, presence of alunite and native sulphur deposits. Ore mineralization, where present, is structurally controlled and very limited, usually of small dimensions.

## DISCUSSION AND CONCLUSIONS

Geological evidence at Cerros Bravos suggests that precious metals mineralization occured at the margins of a caldera and was associated directly with caldera activity. This proposition is based on the fact that the volcanic complex is formed by thick deposits of extrusive volcanic rocks and bordered by subvolcanic domes and epithermal mineralization, which is a common feature of calderas (Lipman, 1984). As well, all known ore deposits and prospects exhibit very similar characteristics and ages, indicating that they were formed at approximately the same time. Contemporaneous volcanic, intrusive and hydrothermal activity is typical of caldera environments, where mineralization generally takes place during the late stages of the caldera evolution, lasting up to two million years after caldera formation (Rytuba,1992; Lipman, 1984). Later resurgent volcanic activity, usually of more intermediate composition, is represented by Cerros Bravos volcanic rocks, dacitic to andesitic lavas associated with stratovolcanoes, which cover most of the caldera and other regional structures. This late stage of volcanic activity is also a common feature of caldera environments (Rytuba, 1992).

Presence of ring fractures at caldera margins are a typical feature of similar deposits elsewhere, but do not occur at Cerros Bravos. The absence of observable ring fractures can be accounted for by two reasons:

i) Development and formation of the caldera used preexisting structures to evacuate material and collapse. In these cases, a caldera relates its geometrical form and activity to regional structures (Rytuba, 1992).

ii) Ring fractures and most regional structures are covered by late volcanic activity of the Cerros Bravos.

Caldera-related epithermal mineralization in the Cerros Bravos district is characterized by silver-gold deposits hosted by Triassic to Jurassic sediments and Miocene volcanic and subvolcanic dacitic rocks. Ore mineralization took place in the early Miocene time (Can Can, Coipa and Esperanza), at the margins of the Cerros Bravos volcanic complex. Ore mineralogy and alteration combined with the absence of adularia, indicate that all mentioned ore deposits and prospects are of acid sulphate (Heald et al., 1987) or high-sulphide epithermal type (Bonham, 1988).

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