THE METALLOGENESIS OF THE VALLE DEL CURA

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Abstract

Valle del Cura (VdC) is a morphologically distinct topographic feature located in the high Andes of the San Juan Province, Argentina, which adjoins the El Indio volcanic belt of Chile.
Recent exploration has confirmed the presence of gold and silver mineralization in several prospects along the VdC; hosted by the volcanic series, which show geographic, geologic, stratigraphic and structural continuity with El Indio belt.
The prospects are from south to north: El Carmen, Río Frío, Sancarrón, Veladero, Lama, Ortiga, Jagüelito, and Taguas among others; several of which have received recent exploration drilling.
Presently, Veladero appears to be the most important prospect as the mineralization comprises 5.85 M Oz Au and 73 M Oz Ag; indicated reserves; the economicity of which is being studied. Exploration continues.
Preliminary data regarding the mineralization present in these prospects is presented. The various geometries: dissemination in fractures, pipe-like features, veins, etc; distinct metal distributions within alteration patterns and other characteristics of the prospects and their genesis are discussed. Comparisons with available data from Au/Ag mines located in the El Indio belt are attempted.

Introduction

The metallogenesis of the VdC is preliminary described. Volcanic rocks of Tertiary age and alteration zones with precious metals mineralization have received recent exploration on the Argentinean side of the Andean Cordillera. The El Indio belt Sillitoe (1991), in Chile, adjoins and is correlative with the Tertiary rocks of the VdC Jones et al. (1999), and has been explored for decades. Together with the Maricunga belt is included within the Early-Middle Miocene metallogenic belts by Sillitoe (1991).
The VdC is morphologically defined by a southern closure, at the Agua Negra pass, to the south of which the Tertiary stratigraphy bifurcates to the SE along the Cordillera de Olivares continuing south to the Valle de los Patos region, see annexed figure. Depth of erosion due to Pleistocene glaciation similar to that described for Chile, Sillitoe (1991, p. 1199) appears to have exposed deeper stratigraphy levels towards the Pachon-Los Pelambres region. The Cordillera de Colangüil mostly formed by Paleozoic sediments and Permo-Triassic intrusives of batholitic dimensions and correlative volcanic rocks of the Choiyoi Group; constrains the development of the Tertiary volcanism of the VdC to the east. The same geology appears to form the basement of the volcanic stratigraphy from about 27 to 32°S, Jones et al. (1999) and annexed figure.
To the north, the VdC extends morphologically to the Cerro El Toro. From the Agua Negra pass to the Cerro El Toro, about 50 Km., Tertiary volcanic rocks correlative to the Doña Ana and Cerro de las Tortolas formations Jones et al. (1996-1999) contain the following prospects from south to north: El Carmen, Río Frío, Sancarrón, Veladero, Lama and Taguas close to the water divide that separates Chile and Argentina and Ortiga, Despoblados, Jagüelito and others closer to the Cordillera de Colangüil.

On the Argentine, to the north of Cerro El Toro the Tertiary stratigraphy is dominated by sediments and red beds, with lesser volcanic and intrusive rocks, forming a continuum which links the El Indio-VdC belt through the Argentine with the Maricunga belt, Jones et al. (1996). In the southern Puna region (annexed figure) Plio-Pleistocene volcanism covers Tertiary volcanic rocks within the La Rioja province of Argentina. The 4000 metre contour which defines the Puna in Argentina, has been shown on the Chilean side, annexed figure, where it forms a physiographic border to the salt-pans east of the Domeyko Cordillera to the latitude of the Nevado de Jotabeche.
Based on previous descriptions the linkages of the El Indio and Maricunga belts with the VdC and related districts in Argentina are evident.

Metallogenesis of the Tertiary volcanic belt in Chile and Argentina.

Sillitoe (1991, fig. 2) locates the El Indio and Maricunga metallogenic belts within the same Early-Middle Miocene belt straddling the Argentinean border and extending from Los Pelambres-Pachón region in the south (about latitude 32°S) to the La Coipa region (about latitude 27°S). Much has been the progress in age dating, modeling and general understanding of the Tertiary metallogenesis of the El Indio and Maricunga belts since the early work of Walthier et al. (1985) at El Indio Mine; when Au-Cu veins cymoid loops and direct shipping ore (DSO) grades were described within an Au-As-Cu-Ag system. Jannas et al. (1999) have updated and refined our understanding of these high sulphidization deposit types.
Three principal models emerge from the work done in Chile: a porphyry-gold model; a breccia-hosted model and a vein-type model. The Maricunga belt, Vila and Sillitoe (1991) containing La Coipa, Lobo, Marte, Refugio, Cerro Casale mines and prospects among others; is characterized by the precious metals (Au-Ag) being associated with porphyry style stockwork-mineralization structurally controlled, hosted in rocks of dioritic and various compositions. Porphyry intrusives, updoming and associated strato-volcanoes (Copiapo, Jotabeche, etc.) are developed within a regional graben which includes the Maricunga salt-pan and the Negro Francisco lagoon. The breccia-hosted model is typified by the Tambo deposit. Jannas et al. (1999) have equated the Au-Ag-Cu deficient Tambo ores in barite-alunite quartz-sericite-kaolinite-pirophillite alteration with a Nansatu-ore type suggesting that they are located at a higher-level; closer to surface than the El Indio-type veins, for which Walthier et al. (1985) had estimated depths of formation between 250-800 m below the water-table.
Venting mentioned by Siddley and Araneda at Tambo (1987) also suggests closer proximity to surface. However both deposits El Indio and Tambo are considered by Jannas et al. (1999) to have formed from one parent fluid which produced oxidized ores at Tambo and reduced ores at El Indio.
In Argentina the stratigraphic, physic and geologic continuity between the El Indio belt and the VdC has been described by Jones et al. (1996, 1999). The VdC is floored by Doña Ana and Cerro Tortolas formations which contain most of the alteration zones and prospects to be described. The metallogenesis of these

prospects is only commencing to be understood but can be preliminarily compared with that of the Early to Middle Miocene Tertiary belt of Chile. The principal prospects to be described are Poposa outside the VdC and Carmen, Río Frío, Sancarrón and Veladero prospects within.

Poposa is located with the Cordillera de Olivares just south of VdC in a large approximately 12 Km^2 alteration zone where various porphyries intrude a quartz-rich sedimentary sequence of Paleozoic age. Fractures and stockworks in the sediments carry gold and appear to be the result of porphyry intrusion in zones of strong argillic alteration. Some of these porphyries: dacites at C° Ismael date by K/Ar in biotites 4.9 $\pm$ 1 My. Breccias at arroyo Chita, few Km East of the Poposa system yielded ages of 8.5 $\pm$ 1 My. However older ages 132 $\pm$ 4 My in andesitic rocks within the prospect, suggest an older basement. Dacitic porphyries drilled 200 m below the valley floor have not been dated and have yielded up to 0.3% Cu values. Enargite-gold veins are developed in the volcanics of Tertiary age (Olivares Fm.), above the 4,000 m elevation, possibly representing the roots of an epithermal lateral to the porphyry style mineralization.

Carmen. The Carmen prospect comprises advanced argillic and argillic alteration zones and was started by drilling high-grade veins which proved to have no depth continuity. Two main alteration zones of acid sulphate affinities with the development of alunite and vugghy silica continue to receive exploration.

The Río Frío alteration zone is mostly developed in fiamme Amiga tuffs of the Doña Ana Formation and contains breccias and vein structures at about 300m above the Tambo Mine site. The geochemistry of the alteration zone shows a very large As-Ag-Hg anomaly with sparse Au values which has been interpreted as high level in the epithermal system. Non mineralized but geochemically anomalous post-mineralization dacitic and rhyolitic porphyries (Cerro Tortolas Fm. ?) are also distinctly post-argillic alteration.

The Sancarrón (Chezanco) prospect is located right at the Chile/Argentina border and extends into Chile to the north. In Argentina previous work includes three tunnels to sample and exploit direct shipping ore (DSO) done during the 1980 decade and three exploration holes drilled below the vein system by Western Mining-Minera Argentina Gold in the nineties. The DSO and locally enargite-rich veins are contained in N-S trending structures parallel to a regional range fault at the intersection of cross-cutting NW-SE trending fractures. These appear to have suffered several reactivations. The vein-structures which have been tested to the 100m depth, are developed in equivalents of the Amiga tuff of the Doña Ana Formation, and contain an inferred reserve of 200,000 oz Au. The continuity of the system at depth is still dubious.

The Veladero prospect has been described regionally by Jones et al. (1996) and in detail by Jones et al. (1999). The prospect is still being explored. Its principal characteristics are the location of gold and peripheral Ag mineralization in a large brecciated system with several pulses of silicification and rebrecciation. The system does not produce a significant clay alteration surface signature, is magnetite destructive and was detected by a combination of methods: geochemistry, geophysics and geology. It has been interpreted Jones et al. (in press) as a diatreme-hosted precious metal deposit of high sulphidization affinities. In discussion is an interpretation that suggests coalescence of two or more diatreme partly obscured by steam-heated barren cover. Zones of higher T are indicated by peripheral intrusives to the SE, and Bi-Mo anomalies at Cerro Pelado. Although suggestions of venting occur at Veladero no lake near associated sedimentation has been described as yet. Hypogene jarosite and hematite often coat breccia vugghs. The alteration often shows siliceous cores grading in depth, laterally and in structures to advanced argillic, argillic and propylitic alteration. The siliceous cores often show several pervasive events which completely obliterate original textures.

The Pascua-(ex Nevada) prospect, Chile, which straddles the border into Argentina at Lama is located 5 Km WNW of Veladero and represents a good example of how elusive the exploration of the systems can be. Exploration commenced around 1977 and it has taken more than twenty years and several companies to achieve a 17 M oz Au reported reserve. Subhorizontal tuff-hosted mineralization discovery at Nevada was followed by the location of mostly covered breccia-related mineralization at Pascua. Together with Veladero reserves in the district exceed 22 M oz Au. To the North of Lama, the Los Amarillos alteration and Taguas, a Cu-rich Au Ag vein system, remain poorly explored and are margined to the east by the Ortiga range where a porphyry gold prospect described by Steven et al. (1998), is found to have affinities with the Maricunga belt.

To the north of the VdC known mineralization includes the Au Ag base-metals prospect explored by Sonoma east of C° Toro, which appears to be hosted by tuffaceous volcanics and red-bed Tertiary sediments. C° Toro constitutes in Argentina the reference point which signals the northernmost development of the VdC region. However, the Tertiary stratigraphy continues northwards straddling the Chile-Argentina border and links the El Indio and Maricunga belts, through Argentina, Jones et al. (1996) and figure. At the Vicuñita prospect (Argentina-Chile) phreatomagnetic, tuff ring related, magmatic and other breccia types, host gold mineralization on an altered zone with dimensions of 10 x 2 Km which is beginning to be explored. On the Chilean SW end of the prospect, siliceous alteration develops on top of low-grade Cu-mineralized porphyries of Tertiary age. Further to the north porphyry-style mineralization characteristic of the Maricunga belt has been found in Argentina (El Dorado and my own observations) at Peñas Negras, Valle Ancho, etc., figure. Peña Negra, where a Cu-Au porphyry is associated with silica-carbonate-sphalerite-Te alteration appears to be a low sulphidization epithermal system also containing Pb-Zn-Bi-As-Ba-Sb, and some telescoping. It is a well known fact that during the late Miocene and early Pliocene, magmatism migrated east from the Maricunga belt into Argentina, Sillitoe (1991). Large amounts of Quaternary volcanism and colluvium obscure Tertiary volcanism east of the Salado river, including the large Bonete-caldera and the attendant dacite-dome fields which outcrop to the NSW and ESE, the basaltic and andesitic flows which extend between this caldera and the Laguna Brava, the Piscis hill, etc. Further east the vocanism and intrusivity within the retroarc (see annexed figure) is locally accompanied by precious metal mineralization of late Miocene-early Pliocene age, and includes: the Farallon Negro vein system, a low sulphidization carbonate-silica-sphalerite-tellurides alteration developed near the Bajo de la Alumbrera-Pampitas-Agua Tapada porphyries; the la Mejicana high sulphidization system where over 50 gold-copper veins overlay porphyry mineralization located along N-S trending structures in the Famatina ranges. Ar-Ar dating Losada Calderon, (1991), shows ages ranging from 5$\pm$ 0.3 to 3.8 $\pm$ 0.2 My. Both veins and porphyries are thought to represent the evolution of a single hydrothermal system. Intrusivity of presumable Tertiary age and associated mineralization is also known in the Precordillera (Hualilan, Gualcamayo, etc.), in the Rio Tendal region, etc. The upper Cenozoic volcanism of the San Luis district, Ramos et al.

(1991) is dated between 1.9 and 6.4 ± 0.6 My. and exemplifies the strong NW-SE trending structure control of some of the mineralized districts in the retroarc. Other examples of this control are the Despoblados-Veladero fault, Jones et al. (1999); the Valle Ancho region, the Valle Fertil lineament, etc. The Leoncito lineament a NW-SE trending feature, see annexed figure, appears to control a major continental break influencing the northern outcrop of the Colangüil batholith, the southern end of the Puna region and affects the 4000 m topographic contour in Chile. Kay et al. (1988) have shown that the migration of volcanic and intrusive activity from 28°-33° S into the retroarc during the Tertiary is associated with shallowing of the subducting plate. Jones (1990), Ramos (1995) suggested the prospectivity of the retroarc region for precious metals.

Discussion

Within the early-middle Miocene metallogenic belt of Sillitoe (1991), the break-up of the Farellones plate (26 My) and basement blocks control changing structural styles and metallotects, (Mpodozis, 1998). As a result, the El Indio and Maricunga belts have similar magmatic pulses but different mineralization events, (Mpodozis, 1998). Within the Maricunga transect, (Kay, 1998) volcanic arc migration east and crustal shortening tend to locate mineralization at the wanning stages of magmatic episodes. Within this tectonic framework, as explorations and investigations continue, high sulphidization models are progressively better known, (Turner, 1997; Jannas et al. 1999), etc. Prospects within the VdC show high sulphidization characteristics, and the same parent fluids can produce oxidized or reduced end results, (Jannas et al., 1999). Prospects in the oriental extension of magmatism from Maricunga into the retroarc: Peña Negra, Farallon Negro; show low sulphidization affinities, possibly representing larger proportions of meteoric waters in the mix magmatic-meteoric fluids.

Veladero is a breccia related model, where the peculiarities include both the size, in area and depth, of the silicification and the relations of the various Si-types with the "steam heated" (S-bearing porus silica) alteration. In high sulphidization systems steam heated alteration often caps or partially overlies other alteration styles; being a lower T event; its geometry and relation with vugghy silica, caps or roots of advanced argillic alteration, remains crucial to the understanding of the system. Fluids producing steam heated alterations can migrate laterally, vertically, collapse into the system at least locally and occasionally host younger mineralization. Nevertheless more porous-vugghy sectors of silicification normally contain the oxides and better mineralized sectors in Veladero and other high sulphidization systems. These possible variations should support exploration around known epithermal districts for years to come.

Conclusions

Both the Maricunga and El Indio Tertiary volanic belts extend into Argentina with similar metallogenic characteristics. El Indio belt extends into VdC, Jones et al. (1996). The Maricunga belt extends to the Peña Negra region and is covered by Quaternary volcanism of the Cerro Bonete-Piscis Puna region of La Rioja and Catamarca. Within the retroarc from about 27°-33° S, see annexed figure, a region of shallowing of the plate-subduction angle during the Tertiary, NWSE trending structures control magmatism and attendant mineralization. Some of these are reactivated pre-Triassic basement fractures. High sulphidation mineralization in high-level breccias at Veladero, high-grade veins at Sancarrón in the VdC region compare to similar mineralization modeled by Jannas et al. (1999) at El Indio Belt.

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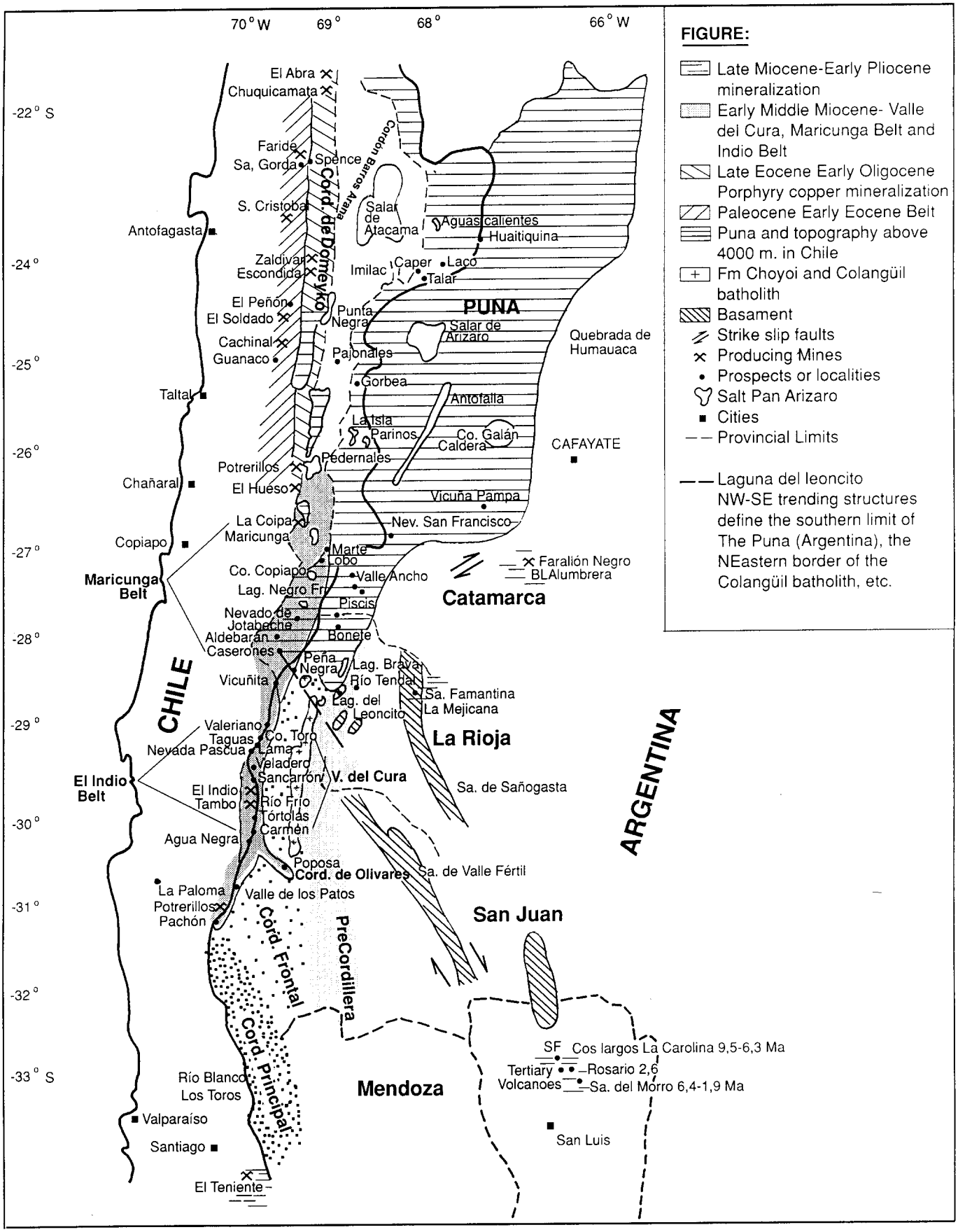
70° W
69°
68°
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-22° S
-24°
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-31°
-32°
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El Abra
Chuquicamata
Faride
Sa, Gorda
Spence
Cordon Barros Arana
Cord. de Domeyko
S. Cristobal
Salar de Atacama
Aguas calientes
Huaitiquina
Antofagasta
Zaldivar
Escondida
Imilac
Caper
Laco
Talar
El Peñon
El Soldado
Punta Negra
PUNA
Salar de Arizaro
Quebrada de Humauaca
Cachinal
Guanaco
Pajonales
Taltal
Gorbea
Antofalla
La Isla
Parinos
Co. Galán
Caldera
CAFAYATE
Pedernales
Potrerillos
Chañaral
El Hueso
Vicuña Pampa
La Coipa
Maricunga
Nev. San Francisco
Copiapo
Marte
Lobo
Faralión Negro
BLAlumbrera
Co. Copiapó
Valle Ancho
Maricunga Belt
Lag. Negro Fr.
Catamarca
Piscis
Nevado de Jotabeche
Bonete
Aldebarán
Caserones
Peña Negra
Lag. Brava
CHILE
Vicuñita
Río Tendal
Sa. Famantina
La Mejicana
Lag. del Leoncito
Valeriano
Taguas
Co. Toro
La Rioja
Nevada Pascua
Lama
Veladero
Sancarrón
V. del Cura
El Indio Belt
Sa. de Sañogasta
El Indio
Tambo
Río Frío
Tórtolas
Carmen
ARGENTINA
Agua Negra
Poposa
Cord. de Olivares
Sa. de Valle Fértil
La Paloma
Valle de los Patos
Potrerillos
Pachón
Cord. Frontal
PreCordillera
San Juan
SF Cos largos La Carolina 9,5-6,3 Ma
Tertiary Rosario 2,6
Volcanoes Sa. del Morro 6,4-1,9 Ma
Río Blanco
Los Toros
Cord. Principal
Mendoza
Valparaíso
Santiago
San Luis
El Teniente
FIGURE:
Late Miocene-Early Pliocene mineralization
Early Middle Miocene- Valle del Cura, Maricunga Belt and Indio Belt
Late Eocene Early Oligocene Porphyry copper mineralization
Paleocene Early Eocene Belt
Puna and topography above 4000 m. in Chile
Fm Choyoi and Colangüil batholith
Basament
Strike slip faults
Producing Mines
Prospects or localities
Salt Pan Arizaro
Cities
Provincial Limits
Laguna del leoncito
NW-SE trending structures define the southern limit of The Puna (Argentina), the NEastern border of the Colangüil batholith, etc.