

EPITHERMAL SILVER-GOLD MINERALIZATION AT THE ESPERANZA AREA, MARICUNGA BELT, HIGH ANDES OF NORTHERN CHILE

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ABSTRACT

The volcanic and sediment-hosted precious-metal prospects in the Esperanza alteration area are located between 4,000 and 4,200 m elevation in the northwestern part of the Maricunga Au-Ag metallogenic belt, High Andes of northern Chile. This region consists essentially of Miocene compound stratovolcanoes of calc-alkaline nature unconformably overlying an igneous and sedimentary basement of Paleozoic and Mesozoic ages.

At Esperanza, rocks of two main geologic units have been affected by hydrothermal activity probably associated with the emplacement of a dacite flow-dome complex: Upper Triassic clastic sedimentary rocks of the La Ternera Formation and upper Oligocene-lower Miocene dacite volcanoclastics and pyroclastics of the Esperanza unit. Reverse and normal faulting affect these units.

Structurally and lithologically controlled Ag mineralization is confined to silicified tectonic and hydrothermal breccias (e.g. Chimberos prospect) and to permeable ignimbrite horizons (e.g. Arqueros prospect) hosted by Triassic and Middle-Tertiary units respectively. Micron-sized Au mineralization is superimposed as a late metallization event, but is restricted to vein-like, NNE - to NW - oriented silicified structures. A vertically zoned hypogene ore zone which underwent deep *in situ* supergene oxidation is proposed for the Ag mineralized breccia at Chimberos prospect, where no sulfide precursors to the oxidized Ag ore were identified. The Chimberos breccia contains a proven reserve of 4.3 million metric tons averaging 320 g/t Ag and 0.14 g/t Au at a 150 g/t Ag cut-off.

The anomalous quantities of Hg, Sb, As, Bi, Ba and Pb that accompany Ag/(Au) mineralization, as well as the associated advanced argillic and argillic alteration assemblages provide evidence for an acid-sulphate, epithermal type mineralized system at Esperanza.

Key words: Epithermal mineralization, Silver, Gold, Hydrothermal alteration, Triassic sediments, Miocene volcanism, Esperanza area, Maricunga belt, Atacama Region, Chile.

RESUMEN

Los prospectos de metales preciosos albergados en rocas volcánicas y sedimentarias de la zona de alteración hidrotermal de Esperanza se ubican entre los 4.000 y 4.200 m de altitud en la parte noroccidental de la franja metalogénica de Maricunga, Alta Cordillera del norte de Chile. Esta región está constituida, esencialmente, por estrato-volcanes miocenos de composición calcoalcalina que cubren, discordantemente, un basamento ígneo y sedimentario de edades paleozoicas y mesozoicas.

En Esperanza, rocas de dos unidades principales están afectadas por alteración hidrotermal asociada probablemente con el emplazamiento de un complejo de domos dacíticos: rocas sedimentarias clásticas de la Formación La Ternera asignadas al Triásico Superior y rocas volcanoclasticas y piroclásticas dacíticas de la Unidad Esperanza, asignadas al lapso Oligoceno superior-Mioceno inferior. Fallamiento inverso y normal afecta a ambas unidades.

La mineralización de Ag está controlada estructural y litológicamente y se emplaza en brechas tectónicas e hidrotermales intensamente silicificadas (Prospecto Chimberos) o en horizontes de ignimbrita permeables (Prospecto Arqueros), encajados en las unidades del Triásico y Terciario medio, respectivamente. La mineralización de Au, de grano muy fino, se superpone como un evento tardío, restringido a estructuras vetiformes silicificadas de orientación NNE y NW.

En la brecha mineralizada de Chimberos, se considera una zonación vertical de la mineralización hipógena, que sufrió una oxidación *in situ* profunda. En Chimberos no se han identificado sulfuros precursores de la mineralización oxidada de Ag.

La Brecha de Chimberos contiene reservas probadas de 4,3 millones de toneladas métricas con una ley media de 320 g/t Ag y 0,14 g/t Au para una ley de corte de 150 g/t Ag.

Las cantidades anómalas de Hg, Sb, As, Bi, Ba y Pb, que acompañan la mineralización de Ag-(Au), así como su asociación con alteración argílica y argílica avanzada evidencian, en Esperanza, un sistema mineralizado epitermal del tipo ácido-sulfato.

Palabras claves: Mineralización epitermal, Plata, Oro, Alteración hidrotermal, Sedimentos triásicos, Volcanismo mioceno, Esperanza, Franja de Maricunga, Región de Atacama, Chile.

INTRODUCTION

The volcanic- and sedimentary-hosted precious-metal prospects at the Esperanza hydrothermally altered area are located in the High Andes of the Atacama Region, at elevations between 4,000 and 4,200 m. It constitutes one of several Au-Ag mineralized areas in the northwestern part of the recently defined Maricunga metallogenic belt (Vila and Sillitoe, in press; Fig. 1).

The geomorphology of the area is characterized by a western, north-south-trending chain of Miocene stratovolcanoes, separated from the subparallel easternmost Quaternary locus of volcanism by the Altiplano or Puna, a 30-50 km wide subhorizontal landscape. Large salt lakes or salares, where modern evaporite deposits are presently being precipitated (Salar de Maricunga, Laguna del Negro Francisco), occur in topographically depressed areas.

The hydrothermal alteration area at Esperanza, characterized by an intense reddish-brown color anomaly, was identified in 1980-1981 through a

grass-roots exploration program designed to locate potential El Indio-type gold mineralized zones. Exploration started with an aerial reconnaissance along the Andes of northern Chile by BT Exploraciones Ltda. on behalf of Minera Anglo Cominco Ltda. (ANCOM), a joint venture between Minera Anglo American Chile Ltda. (MAAC) and Minera Cominco Resources Ltda. Based on anomalous Ag values found in silicified outcrops at Esperanza during ground reconnaissance, a soil geochemical survey on an 80 x 40 m grid was conducted during the 1981-1982 field season, covering most of the altered area (6 x 3 km). As a result of this survey, six main Ag soil anomalies (>1.0 ppm Ag) were defined, namely Chimberos, Huantajaya, Potosí, Arqueros, Bonanza, and Santa Rosa prospects. Construction of access roads and bulldozer trenching on the soil anomalies was followed by detailed geologic mapping and rock-chip sampling, as well as by drilling and tunneling in the Huantajaya, Chimberos and Arqueros prospects during the 1982

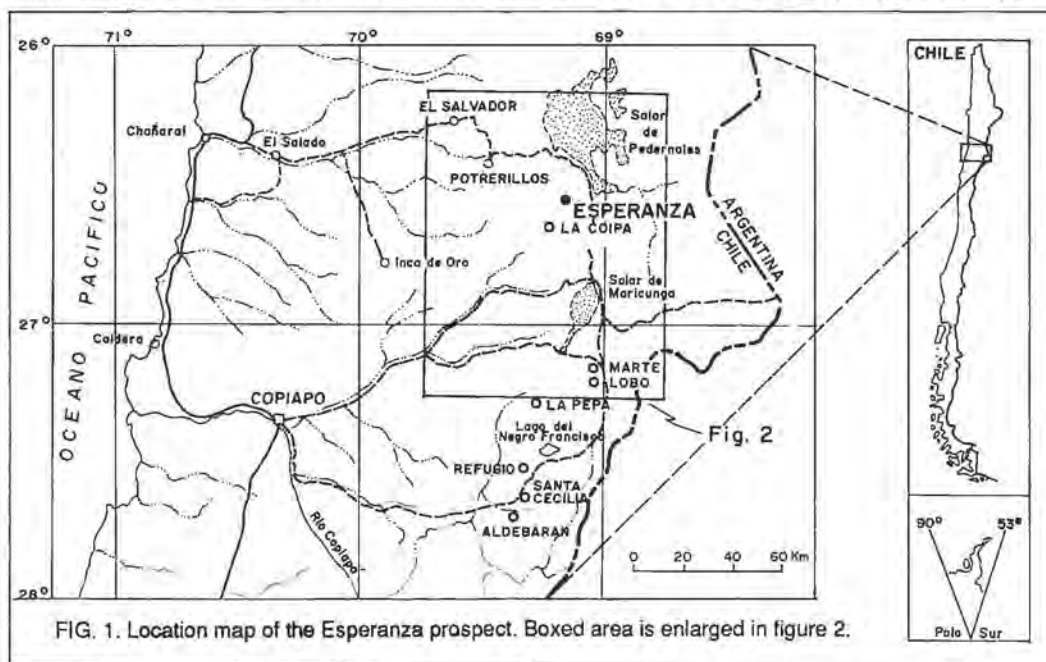


FIG. 1. Location map of the Esperanza prospect. Boxed area is enlarged in figure 2.

to 1986 field seasons.

Exploration at Chimberos prospect included 4 levels of adits (ca. 2.5 km), 800 m of diamond drilling and 4,400 m of reverse circulation drilling. At Santa Rosa and Potosí prospects, only geologic mapping and rock sampling with limited reverse circulation drilling have been carried out.

As a consequence of this effort, a 4.3-million metric tons oxidized mineral deposit averaging 320 g/t Ag and 0.14 g/t Au was defined at Chimberos, while

two systems of NNE and NW-oriented Au-(Ag)-bearing siliceous replacement veins were identified at Arqueiros and Huantajaya prospects, respectively.

Considering that the brief outline of the Chimberos deposit presented by Colley *et al.* (1989) is based only on preliminary MAAC exploration data and their own very limited fieldwork, detailed descriptions of the Chimberos and Arqueiros deposits are necessary and presented below.

REGIONAL GEOLOGICAL SETTING

The regional geological setting in which Esperanza is located has been described by Segerstrom (1968), Zentilli (1974) and more recently by Mercado (1982), Aguilar (1984), Zamora (in prep.) and Davidson and Mpodozis (in press). Although no metallic deposits were known in the region prior to 1980, its potential for precious metals was suggested previously by Zentilli (1975) and Llaumet and Henríquez (1976).

Esperanza lies in the southern part of the Andean Central Volcanic Zone (CVZ; Thorpe *et al.*, 1982), within the Maricunga belt (Vila and Sillitoe, in press), a NNE oriented Au-Ag metallogenic province which consists essentially of large Miocene compound stratovolcanoes of calc-alkaline nature, unconformably overlying an igneous and sedimentary basement of Paleozoic and Mesozoic ages. Discrete episodes

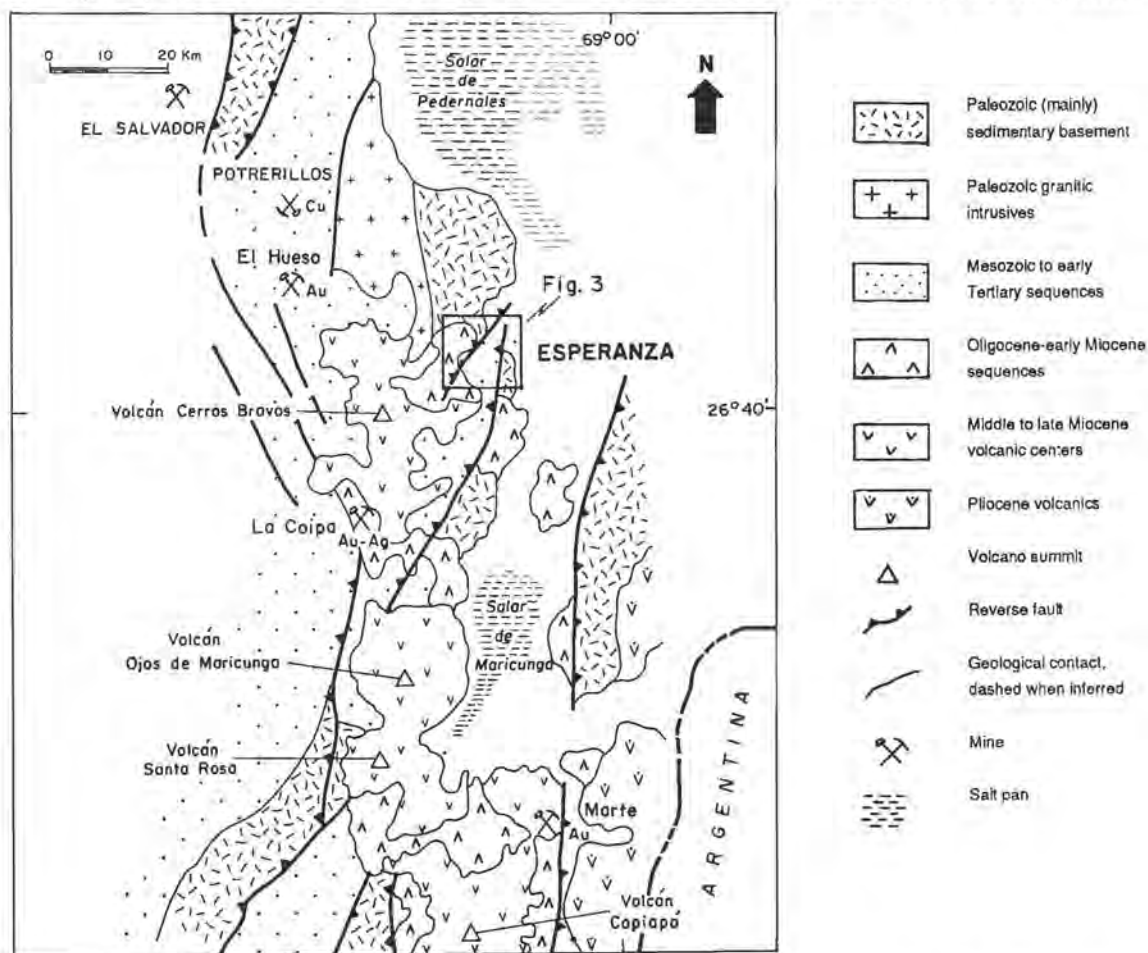


FIG. 2. Regional geological setting of the Esperanza area in the northern half of the Maricunga Belt (from Davidson and Mpodozis, in press). Boxed area indicates the hydrothermal alteration extension.

of regional high-angle reverse faulting of late Cretaceous and early Miocene ages, resulted in compressional horsts and grabens, mainly of NNE orientation. Upfaulted blocks of pre-Andean and

Jurassic to lower Tertiary rocks also occur as NNE elongate strips, mainly along the western border of the Maricunga belt (Fig. 2).

GEOLOGY OF THE ESPERANZA AREA

The hydrothermal alteration at Esperanza is probably related to the emplacement of a largely concealed dacite porphyry flow-dome complex. Rocks of two main lithological units are affected: 1. Clastic sedimentary rocks of the Triassic La Ternera Formation (Brüggen, 1950, Zamora, in prep.), which crop out in the eastern half of the altered area, and 2. The overlying late Oligocene-early Miocene dacitic volcanoclastics and pyroclastics which cover most of the western part (Fig. 3). The latter rocks, which are here named informally as the Esperanza Unit, are widespread distributed and are, in general, intensely hydrothermally altered. South of Esperanza, chronological and compositional equivalent rocks constitute an important host-rock for Au-Ag mineralization (e.g. Santa Cecilia, La Pepa, La Coipa; Vila and Sillitoe, in press). In the Esperanza area, they are overlain by middle Miocene (14-15 Ma) andesitic lava flows of the Cerros Bravos stratovolcanic complex (Cisternas, 1977; Zamora, in prep.)

STRATIFIED ROCKS

The lowest exposed part of the La Ternera sedimentary section crops out on the northern slope of Chimberos hill. It is relatively unaltered and comprises a minimum of 100 m of green, matrix-supported monomictic conglomerate with no visible stratification. The conglomerate is composed mainly of subrounded fragments of silicified sandstone, shale and granite in a coarse-grained, chlorite-rich sandy matrix constituting 20-30% of the total volume. Epidote is also common. This sequence grades upward to a 120 m section of yellowish-brown sandy conglomerate containing well-rounded, strongly silicified sandstone and milky quartz fragments. The matrix, 60-70% in volume, consists of coarse quartz-rich sandstone.

The upper part of the sedimentary sequence crops out at Santa Rosa and on the southern slope of Chimberos hill, and is represented by 400 m of light

gray, medium to fine grained sandstones and siltstones with thin lenticular intercalations of pebble conglomerate, black shale and fossiliferous limestone. Well-sorted detrital quartz (0.15 mm) in a matrix of fine authigenic clay is characteristic for most of these rocks, along with fragments of plagioclase, volcanogenic lithics, muscovite (altered to chlorite) and carbonaceous-ferruginous matter.

The Esperanza Unit overlies the basal sedimentary sequence with angular (and erosional?) unconformity, and comprises most of the hydrothermally altered rock at the area. It is composed mainly of light brown to yellowish crystal and lithic tuff, block and ash flows and volcanoclastic breccias with intercalations of lapilli and weakly welded ignimbrite as well as thin lenticular layers of lacustrine volcanic sandstones. These rocks have been deposited in depressions in a rugged paleotopography and locally may be folded weakly; the minimum thickness is estimated at 500 m.

According to stratigraphic and structural relationships, the Esperanza Unit is considered equivalent to the Quebrada Carrizo sequence (Bruce, 1989), south of Laguna del Negro Francisco area, and to the Villalobos sequence (Gardeweg and Mpodozis¹) on the northern slopes of the Volcán Copiapó.

Overlying the Esperanza Unit with an angular unconformity, a thick post-alteration-mineralization volcanic cover crop out, represented by dark green dacites to rhyodacites and rhyolitic ignimbrites. These are assigned to the Cerros Bravos volcanic complex of middle to late Miocene age (15.0 ± 0.6 Ma; Zentilli, 1974).

Finally, a lacustrine sequence of probable Pliocene age is preserved in the area as remnants of 30-50 m thick horizontal volcanosedimentary beds of alternating volcanoclastic and coarse grained volcanic sandstones.

FLOW-DOME COMPLEXES

Intense hydrothermal and supergene alteration

¹ 1990. Geología regional entre los prospectos Lobo y Soledad, Franja de Maricunga, Cordillera de Copiapó. Minera Anglo American Chile, Ltda. (Unpublished report), 179 p. Santiago.

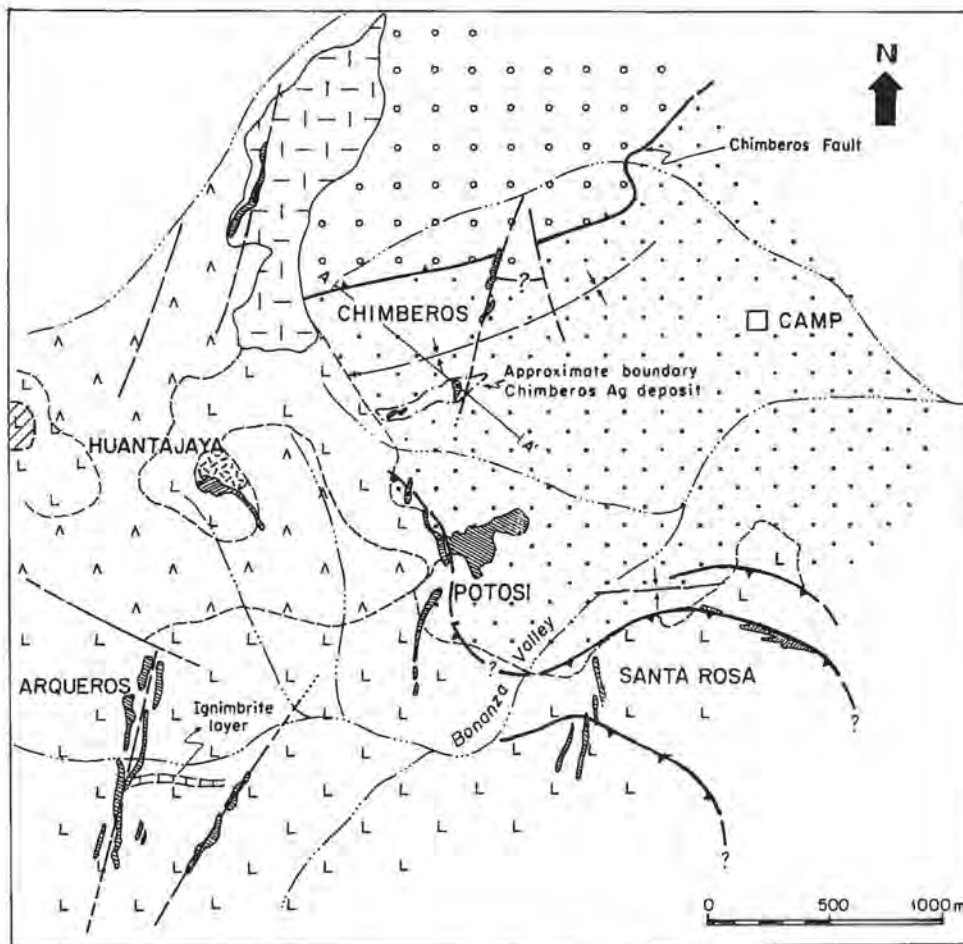
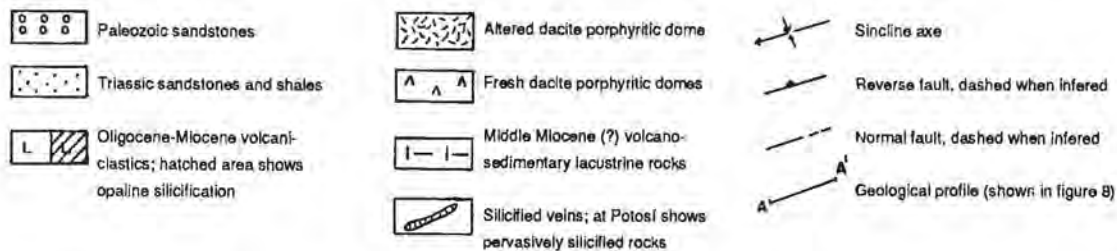


FIG. 3. Generalized geological map of the Esperanza prospect.

of the Huantajaya hill area largely preclude recognition of primary textures. Nevertheless it is believed that at least part of this area is underlain by a pre-mineralization porphyritic dacite flow-dome (Sillitoe²). Porphyritic textures, well-developed quartz-eyes and flow-banding have been recognized near the summit of the hill. Part of the volcanoclastic and pyroclastic rocks of the Esperanza Unit may be related to the

dacite flow-dome(s) emplacement.

Following the alteration and associated mineralization at Esperanza, several apophyses of relatively fresh flow-banded dacite constituting one or more domes (Sillitoe²), were emplaced at the central part of the hydrothermal altered zone. The main dacite porphyry apophysis exhibits well-developed, inward-dipping flow banding that defines an inverted conical

² 1985. Examination of gold-silver prospects at Aldebarán, Esperanza, Pantanillo and Marte, Chile. Minera Anglo American Chile Ltda. (Unpublished report), 26 p. Santiago

form. The rock is porphyritic and shows a bimodal size distribution of phenocrysts (40 vol%) dominated by plagioclase and accompanied by conspicuous round quartz, hornblende, and biotite; alignment of crystals is present.

STRUCTURE

The structural setting is dominated by ENE and WNW-trending reverse faulting of probable early Miocene age that places Paleozoic metasediments over La Ternera Triassic sandstones (Chimberos fault) along the northern slope of Chimberos hill. La Ternera Formation sedimentary rocks exhibit regional N30°W/20°S monoclinical attitude, although intense folding is present locally at Chimberos, Potosí and Santa Rosa hills as a result of the reverse faulting (Fig. 3).

Younger, normal fault systems of NNE and NW orientation are also present in the area, controlling a group of siliceous replacement veins.

HYDROTHERMAL ALTERATION

The hydrothermal alteration at Esperanza shows clear structural and lithological controls. Moderate to intense, albeit patchy silicification with subordinate alunite and barite is present as vein-like fracture fillings or subvertical breccia bodies along the reverse and normal fault zones. Wall-rock alteration is characterized by district-wide argillization, with halos of kaolinite and alunite close to the silicified areas. These halos show a greater lateral extent when developed within the Esperanza Unit, which in turn is extensively oxidized, limonitized, and bleached, probably due to a high original and secondary permeability. Within the unit, nonwelded ignimbrite and lapilli tuff layers are commonly affected by more intense, quasi-stratabound-like silica-alunite alteration.

Remnants of pervasive silicification, characterized by milky white to pink opaline silica selectively replacing parts of the uppermost layers of the Esperanza Unit, are present west of the Huantajaya hill area (Fig. 3). This replacement zone is considered to have originated in close association with a paleowater-table (Sillitoe²) and is represented by an opaline horizon that probably was formed over most of the altered area prior to erosion.

SOIL GEOCHEMISTRY

As mentioned previously, the soil geochemical survey over the Esperanza area identified six main Ag anomalies in the central and eastern parts of the alteration zone that are generally related to silicified outcrops. Silver anomalies show a well-defined north-west trend, and range in size from 100 x 300 m in Chimberos prospect to 300 x 600 m at Huantajaya prospect. Some anomalies exhibit appreciable downslope physical transport (Fig. 4). An apparent but weak ENE orientation of some Zn-Pb geochemical anomalies is also observed at Santa Rosa prospect. Only one small and weak Au anomaly was identified at Arqueros prospect, and it is apparently unrelated to Ag. Moderate to strong Zn anomalies are coincident with Ag at Bonanza and Huantajaya prospects, whereas the main Pb anomaly is centered on Potosí prospect, which also encloses a small Ag anomaly.

MINERALIZATION STYLES

Two district styles of disseminated Ag (with subordinate Au) mineralization are recognized at Esperanza: hydrothermal and tectonic breccia hosted (*e.g.*, Chimberos prospect), and stratabound ignimbrite-hosted (*e.g.*, Arqueros prospect). Gold (with subordinate Ag) mineralization is restricted to steep, NNE- and NW-striking vein-like silicified structures present mainly in Arqueros and Huantajaya areas. These structures, which at Arqueros are superimposed on the ignimbrite horizon, are considered to be the conduits through which most of the hydrothermal, mineralizing fluids ascended (Fig. 5).

Another style of Au mineralization, poorly exposed at Carachitas valley in the southernmost part of the alteration area, occurs as weak disseminations in a stockwork of banded, millimeter-size, dark and translucent quartz veinlets, cutting an intensely argillized dacite porphyry. A coincident, although weak Au-Cu-Pb geochemical expression, which is distinctive for disseminated porphyry-type Au-(Cu) mineralization throughout the Maricunga belt (Vila and Sillitoe, *in press*), characterizes the stockwork area.

AGE OF ALTERATION-MINERALIZATION

K-Ar dating (Sillitoe *et al.*, *in press*) of the alteration-mineralization processes, as well as of the post-

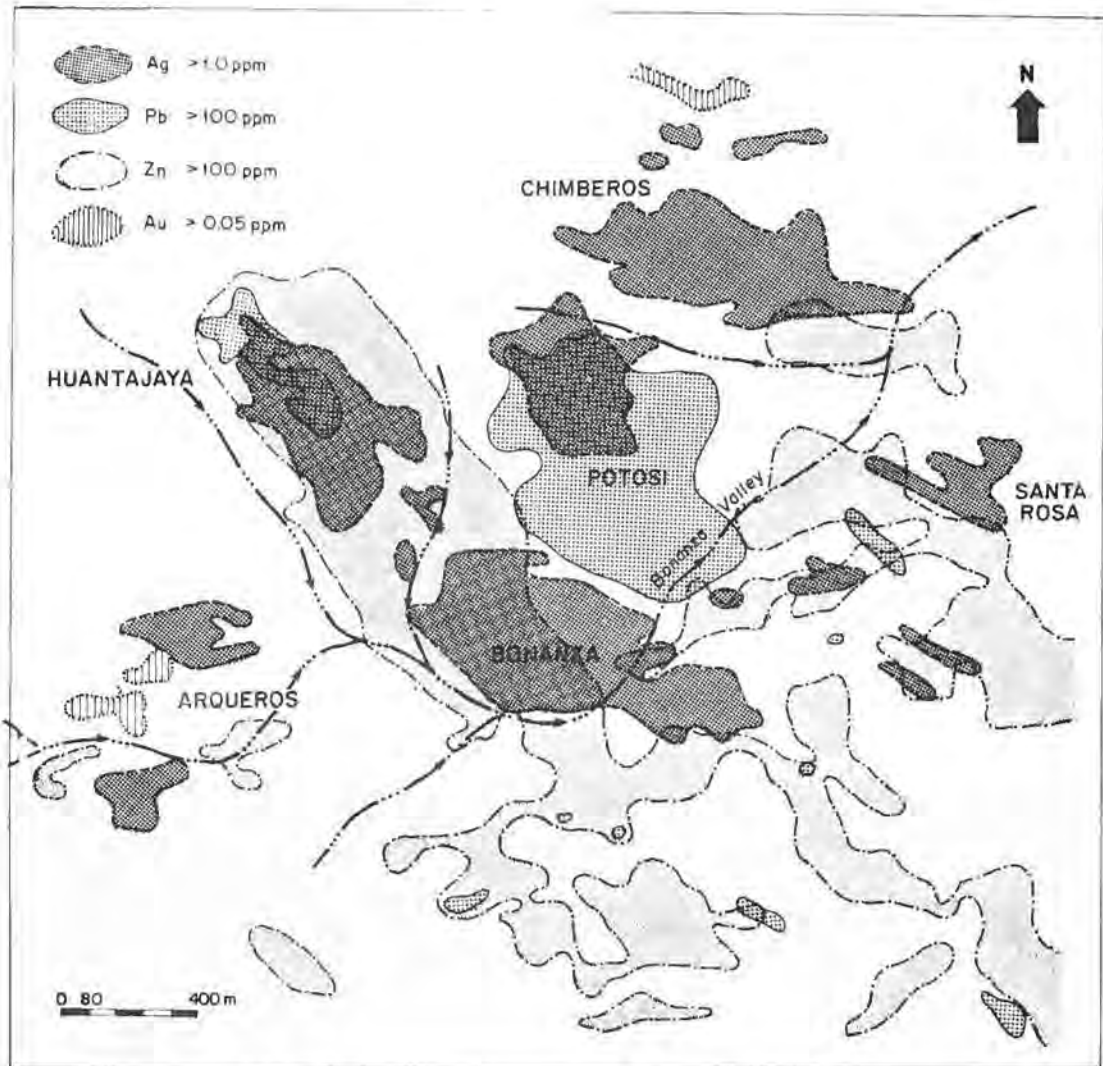


FIG. 4. Soil geochemical anomalies in the Esperanza prospect.

mineralization dacite dome at Esperanza indicates a sequence of intrusive, volcanic, and hydrothermal events that spanned from at least 24- 20 Ma, with dome emplacement and related hydrothermal activity occurring close to 23 Ma. The 23.2 ± 0.7 and 20.7 ± 0.7 Ma ages obtained from hydrothermal alunite at Arqueros and Potosí prospects, respectively, suggest that mineralization and alteration occurred within a 3 Ma period. The fresh post-alteration dacite dome at Huantajaya prospect yielded a 20.2-1.0 Ma age (Sillitoe *et al.*, in press). The early Miocene age ascribed to alteration-mineralization at Esperanza is consistent with the western metallogenic sub-belt defined in the Maricunga belt (Vila and Sillitoe, in press).

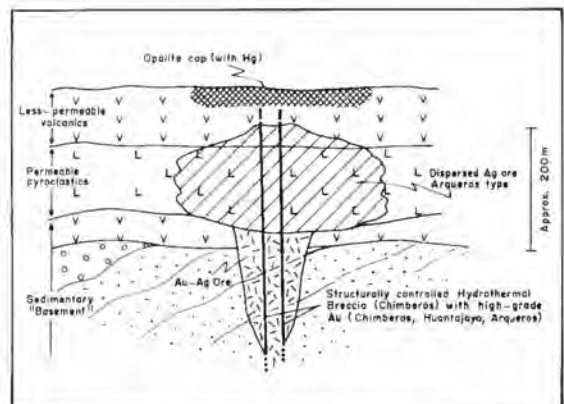


FIG. 5. Schematic characterization of the different mineralization styles at Esperanza (from Sillitoe').

THE CHIMBEROS SILVER MINERAL DEPOSIT

The Chimberos Ag mineral deposit is developed within intensely silicified and brecciated Triassic sedimentary rocks along the southern slope of Chimberos hill. Silver is the only metal of economic importance. Its surficial expression corresponds to a 50 x 40 m, dark-brown, intensely silicified, oxidized, leached, and brecciated outcrop, which stands out from the argillized sedimentary country rock. A group of smaller, ENE-trending silicified outcrops occur at the southwestern part of Chimberos hill, while NNE fault-related silicified zones are present north of the main outcrop. The ENE and NNE linear configuration of the silicified zones at surface, subparallel to the northward dipping trace of the Chimberos reverse fault, and to the general NNE structural trend, respectively, suggests strongly a structural, fault-related control of silicification, with the main outcrop representing the intersection of at least two structures (Fig. 6).

SOIL AND ROCK GEOCHEMISTRY

At Chimberos, only Ag anomalies were detected by soil geochemistry. The east-west elongation of the main Ag anomaly is due apparently to downslope transport from the main silicified outcrop. Silver values range from 1.0 to 16.0 ppm. No significant Au, Pb, Zn, As or Cu soil anomalies are present.

A single soil geochemical sampling transverse from the top of Chimberos hill (4,200 m) to the lowest adit level (4,017 m) shows locally high Cl (500-3,900 ppm) and moderate I (2-15 ppm) anomalies, apparently related to silicification (H. Colley, written commun., 1986).

Although only fragmentary surface rock geochemical data are available from trenches immediately above the Chimberos deposit, some general geochemical relationships may be obtained. Multielement rock geochemical anomalies show a



FIG. 6. General view of the Chimberos Hill looking north. The dark outcrop at the right corresponds to strongly silicified hydrothermally brecciated sandstones and shales. It represents the surficial exposure of the Chimberos Ag deposit.

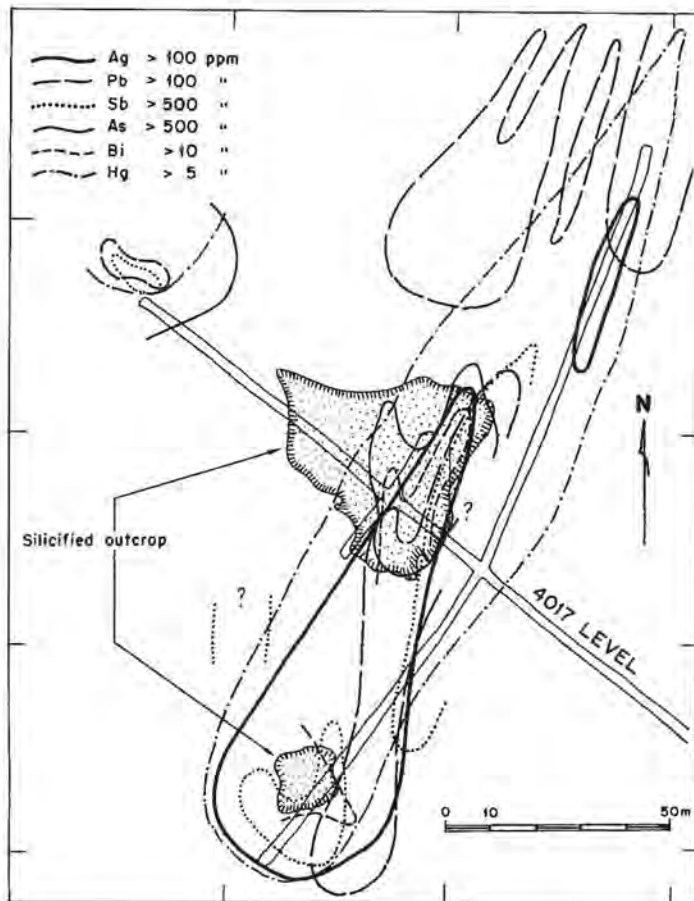


FIG. 7. Rock geochemical anomalies over the Chimberos Ag deposit.

well-defined NNE orientation, the higher values being concentrated along the southern part of the main silicified outcrop (Fig. 7). In this area, where more intense hydrothermal brecciation is observed, highly anomalous Ag (100-500 ppm), As (500-4,000 ppm), Bi (5-50 ppm) and Sb (80-600 ppm) values along with weak Pb (100-200 ppm) and Au (0.05 ppm) anomalies are superposed. This anomalous geochemical assemblage is enclosed by an extensive 200 x 50 m Hg anomaly (> 5 ppm) which includes most of the silicified outcrops in the area. Another small, but very high As anomaly (>0.2% As) coincident with Sb and Pb, is found north of the main anomaly. It appears that the increased contents of Ag and other elements extend outward into the country rock as far as microfracturing are developed. Beyond this area, metal concentrations drop to background values. Approximate enrichment factors in oxidized ore vs. fresh host rocks are: Ag (>300 X), As (>40 X), Bi (>100 X), Sb (>100 X), Hg (>100 X) and Pb (>50 X).

STRUCTURE AND HYDROTHERMAL ALTERATION

Underground workings at Chimberos have revealed the mineralized breccia and host rocks on four levels over a vertical range between 4,150 and 4,000 m. The sedimentary host rocks are intensely fractured and folded into a major syncline with a south-plunging, north-east-directed axis. The superimposition of NNE-trending normal, strike-slip(?) faulting observed at surface, increased the fracture intensity, producing a structurally controlled breccia. The breccia is difficult to recognize macroscopically because of its highly silicified monolithologic character, the tight fit of the angular clasts, the lack of distinctive matrix, and the presence of many large fragments, which were only shattered *in situ* or underwent very little displacement. Well-developed multiple episodes of hydrothermal brecciation is present locally, as relatively small (10 x 5 m) irregular bodies with angular to subrounded fragments in a fine quartz

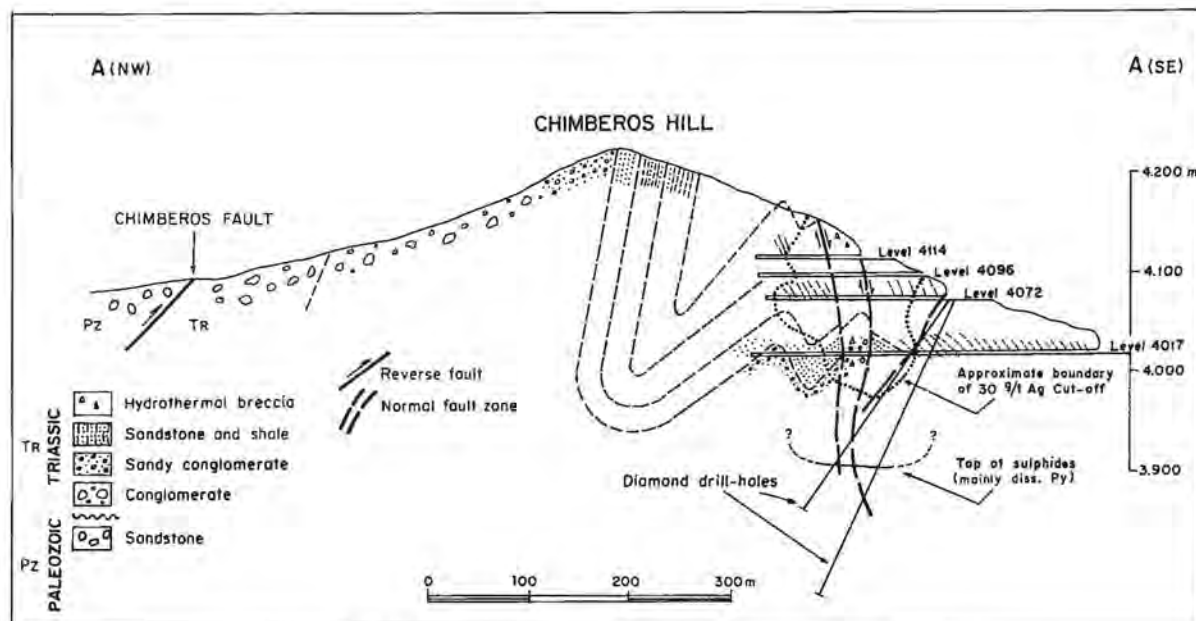


FIG. 8. Schematic cross-section of the Chimberos Hill.

matrix. Open spaces are common through most of these breccia bodies. Silicification largely obliterates original rock textures and mineralogy and is dominated by dark gray recrystallized chalcedonic quartz, locally strained and foliated. Interstitial clay and minor alunite and barite occur intergrown with quartz. Partings in the rock are filled with jarosite, and are banded with laminations represented by horizons of differing quartz grain-size. Pyrite boxworks lined with hematite are also present; open spaces occur locally and are filled by banded silica, gypsum, siderite and jarosite (Lindsay³).

Original bedding in the sedimentary host rocks is difficult to recognize due to moderate to intense, limonite-poor argillization developed as a halo to the silicified breccia. Nevertheless, the available bedding measurements suggest that the host rocks of the Chimberos orebody suffered complex folding as result of north-dipping reverse faulting (Fig. 8). Weak pyrite disseminations and veining occur locally in the northern argillized halo on an intermediate level. Boundaries of silicification are sharp perpendicular to the axis of the breccia but are gradational along its length.

A late magmatic event at Chimberos is represented by narrow, NNE- to NE-oriented, strongly altered dacite dikes and sills which intrude the folded sedimentary sequence. Original mineralogy and

fragmental textures are poorly preserved. Relict fragments are composed of small quartz phenocrysts and irregularly shaped volcanogenic lithics up to 1 cm in size. Both fragments and fine-grained matrix are completely replaced by quartz, alunite and variable amounts of clay, gypsum, and jarosite. The spatial and temporal relationships with the hydrothermal breccias are not clear, although the dikes may be related to the pre-mineralization(?) dacite dome in the nearby Huantajaya area.

MINERALIZATION CONTROLS

The Ag-(Au) mineralization extends for about 400 m along a general north-east strike, is 100 m wide, and up to 150 m deep. Mineralization limits are coincident with those of brecciation and silicification. The NE-trending long axis of the mineralized breccia is subparallel to the reverse faults and folds axis although a downwards progressive clockwise rotation from N50°E to N70°E is observed in the underground workings. A secondary NNE-striking vertical structure is also observed in the eastern part of the mineralized breccia which controls the Au distribution. As a result of this structural control of the mineralization, the northern half of the deposit shows a subcircular shape in cross section which changes progressively to a 40-50°N dipping tabular form in its southern part

³ 1990. Notes on the petrology of selected samples from Esperanza. Minera Anglo American Chile Ltda. (Unpublished report), 9 p. Santiago.

(Figs. 9, 10). At the lowermost adit, a NNE/60°N pre-mineral(?) fault represents the southern limit of the orebody.

SILVER OCCURRENCES AND DISTRIBUTION

The Chimberos Ag orebody is almost completely oxidized, probably aided by the intense fracturing and brecciation. Deep diamond drilling to explore for primary Ag-bearing sulfides revealed that oxidation becomes progressively deeper towards the central part of the breccia body, attaining a depth of 240 m, although Ag grades are lower (30-50 g/t). Hypogene sulfides include remnant pyrite veining with traces of fine-grained argentite. No hypogene Ag-bearing sulfides were identified in oxidized Ag ore at Chimberos.

The argentiferous ore in the Chimberos breccia is extensively silicified, oxidized, leached, and enriched in jarosite, limonite, and a number of silver-bearing minerals. Quartz (94-98 wt.%) accompanied by minor to trace amounts of barite, leucocene, rutile, zircon, garnet, apatite, altered feldspar, alunite, and sericite are the gangue constituents (Glathaa⁴; Tables 1, 2). Quartz is predominantly cryptocrystalline and is characterized by the presence of small vugs (0.1-0.2 mm) lined with botryoidal limonite or barite, which apparently acted as favorable locations for deposition of Ag-bearing minerals.

Eight Ag-bearing minerals and an unknown Sb-Bi-Pb-rich Ag mineral were identified at Chimberos (Glathaa⁴; Table 3). The bulk of these minerals are present as discrete, finely disseminated grains throughout the quartz-rich mass or intricately intergrown with jarositic limonite.

Native Ag is present as very small (< 5 microns) particles which cluster in a chain-like or botryoidal fashion, commonly associated with limonite. Native Ag particles enclosed in cerargyrite, bromerite, or argentite, and associated locally with barite, are also common. Cerargyrite is present as free grains (300 microns) or is included within limonitic material. Iodyrite and argentite (acanthite) particles are generally smaller and are enclosed commonly in cerargyrite or limonite. The unknown Ag compound detected by electron microprobe (Glathaa⁴) appears to be associated preferentially with limonite and, to a lesser extent, with jarosite as discrete particles. Only a few, very small (< 5 microns) pyrite, chalcocopyrite, and gold

particles are encountered, all completely enclosed in quartz.

Limonite (and clay) are present mainly filling fractures and as coatings; disseminations are subordinate. Based on color, at least three main types of limonite are distinguished in the Chimberos ore: red, black and yellow. Jarosite and hematite predominate in red limonite, along with alunite, barite, and gypsum; goethite and hematite predominate in black limonite along with alunite and subordinate amounts of an unknown (Mn-Al-Co) mineral, and jarosite predominates in yellow limonite together with illite-montmorillonite clays. Most of the Ag-rich samples have significant amounts of hematite and/or goethite. Underground workings show a crude lateral zoning from brown-yellowish limonite along the boundaries of the breccia that gradually changes inward to a dark-red and to iridescent black limonite-rich inner zones. An increase in red limonite intergrown with clay is also noticeable in the intermediate levels.

METAL ZONING

On each underground level, Ag isopleths (*e.g.* 30, 70 and 150 g/t Ag) are closely spaced transverse to the long axis of the orebody but more irregular and diffuse in a longitudinal sense and vary sympathetically with the intensity of silicification (Fig. 9). Gold values (1-3 g/t) define steep narrow north-east-oriented zones, which transect the main breccia at oblique angles, generally confined to the most highly brecciated parts of the orebody. The greater permeability of these highly brecciated zones may have focused late-stage, gold-bearing fluids. Ag-Au ratios in Chimberos ore are generally greater than 4,000 although in Au-rich zones, the Ag-Au ratio ranges from 5-100.

In a vertical sense, composites of the richer inner zone taken from three of the underground levels indicate a progressive decrease in the Ag and Cl content with depth, whereas the opposite occurs with SO₄, Fe₂O₃, and K₂O (Table 4). The low K₂O/Na₂O ratio and its progressive decrease upward from 0.86-0.32 suggests the presence of natroalunite in the upper levels of the mineralized breccia. Average Mn contents are low, generally on the order of 0.01 wt.%. XRF analyses of the same samples (Glathaa⁴; Table 5), suggest an increase of Pb and As with depth, while Ba, Sn, Te and Bi are enriched close to surface.

⁴ 1984. Mineralogical examination of three Chimberos samples for the department of gold and silver. Anglo American Corp., Ltda., Research Laboratories (Unpublished report) 7 p. Johannesburg, South Africa.

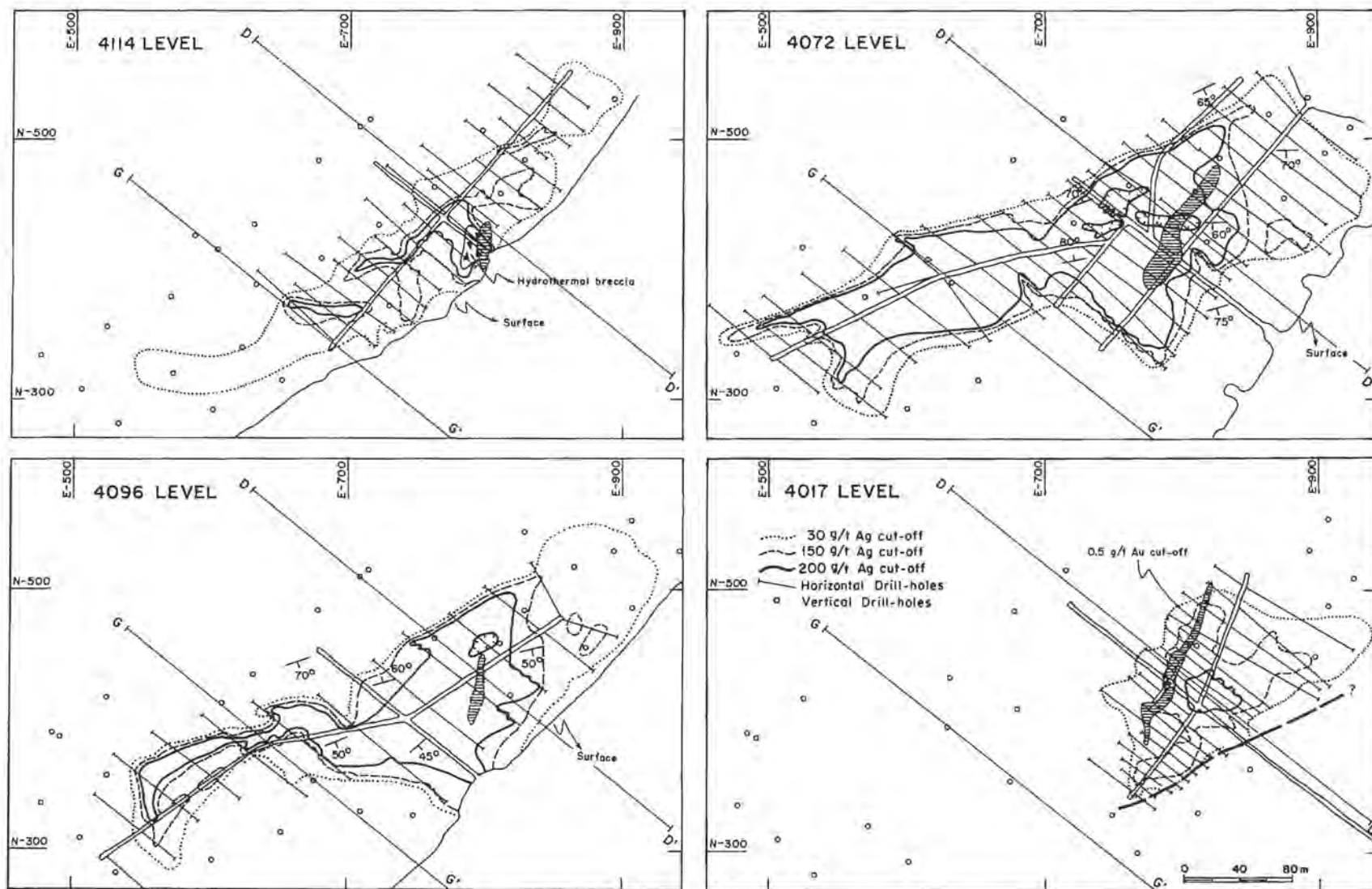


FIG. 9. Horizontal distribution of Ag ore at the four adit levels, Chimberos Ag deposit.

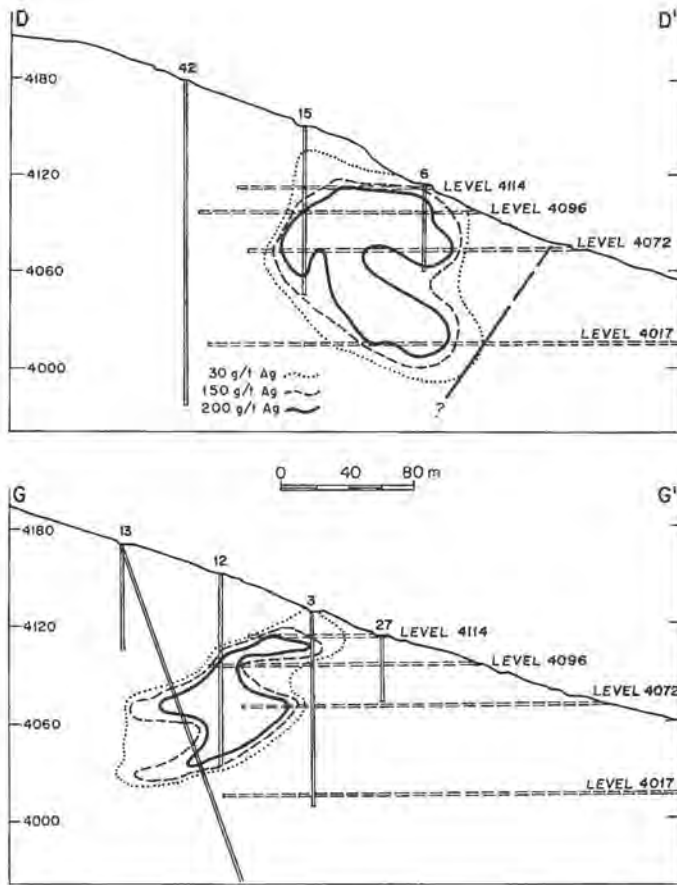


FIG. 10. Profiles of Ag ore distribution, Chimberos Ag deposit.

Analytical data for Ag ore from the lower adit show up to 1.3 wt.% Pb and 1.1 wt.% As, with Pb/Ag ratios on the order of 10-40.

an additional reserve of 2.3 million metric tons averaging 108 g/t Ag was calculated.

ORE RESERVES

Measured reserves at Chimberos are 4.3 million metric tons averaging 320 g/t Ag and 0.14 g/t Au at a 150 g/t Ag cut-off. In the 75-150 g/t Ag cut-off range,

TABLE 1. ESTIMATED MINERAL COMPOSITION, CHIMBEROS Ag ORE*

Mineral	Average (wt.%) at each level		
	4,114 m	4,072 m	4,017 m
Quartz	98.5	98.0	94.0
Limonite	0.5	0.5	2.0
Jarosite	Tr	0.5	2.0
Barite	0.5	0.5	1.0
Other minerals	0.5	0.5	1.0

* Following Glathaar†

TABLE 2. PERCENTAGES OF HEAVY MINERALS, CHIMBEROS Ag ORE*

Mineral	Average (wt.%) at each level		
	4,114 m	4,072 m	4,017 m
Gold	Tr	Tr	Tr
Native silver	6.1	1.2	0.8
Cerargyrite (AgCl)	22.5	5.2	1.4
Iodyrite (AgI)	Tr	1.5	0.4
Argentite (AgS)	Tr	2.0	0.9
Limonite	19.2	48.7	35.9
Jarosite	5.9	10.3	29.2
Barite and other gangue	41.1	19.7	26.1
Rutile/leucoxene	3.7	6.0	5.3
Pyrite	Tr	2.2	Tr
Covellite	-	-	Tr
Zircon	1.5	3.2	Tr
Total	100.0	100.0	100.0

TABLE 3. Ag-BEARING MINERALS IN CHIMBEROS Ag ORE*

Mineral	Composition	Presence
Native silver	Ag	major
Cerargyrite	Ag Cl	major
Embolite	Ag (Br, Cl)	minor
Iodyrite	Ag I	minor
Argentite	Ag ₂ S	minor
Bromerite	Ag Br	minor
Argentojarosite	Ag Fe ₃ (SO ₄) ₂ (OH) ₆	minor
Unknown	Sb-Bi-Pb-Ag-rich	trace
Dyscrasite (?)	Ag ₃ Sb	trace

* Following Glathaar⁴

TABLE 4. CHEMICAL ANALYSIS (AAS) OF CHIMBEROS Ag ORE*

Mineral	Average (wt.%) at each level		
	4,017 m	4,072 m	4,114 m
Ag (ppm)	223	365	1385
Au (ppm)	1.33	0.72	0.60
Cu (ppm)	113	94	226
CaO (%)	0.03	0.02	0.03
MgO (%)	0.02	0.02	0.02
Na ₂ (%)	0.12	0.07	0.07
K ₂ O (%)	0.10	0.05	0.02
Fe ₂ O ₃ (%)	7.53	1.87	1.64
Al ₂ O ₃ (%)	0.47	0.63	0.31
SO ₄ (%)	0.67	0.14	0.12
Cl ₄ (%)	0.09	0.12	0.15
SiO ₂ (%)	86.20	94.36	87.29

TABLE 5. XRF ANALYSES OF CHIMBEROS Ag ORE*

Mineral	Composite average at each level (ppm)		
	4,017 m	4,072 m	4,114 m
Pb	3798	445	203
As	1931	155	248
Ba	290	660	4366
Sn	80	134	319
Te	21	36	46
Ni	6	4	3
Co	28	37	29
Zn	23	4	3
Se	8	3	4
Sb	472	236	418
Bi	178	99	315

THE ARQUEROS GOLD-SILVER PROSPECT

The Arqueros Au-Ag mineralized area is located at elevations between 4,170 and 4,050 m within the Esperanza Unit, which is exposed in the Bonanza valley (Fig. 3). The Esperanza Unit here consists predominantly of subhorizontal, monolithologic volcanic breccias of dacitic composition with a tuffaceous matrix, which are intercalated with epiclastic sediments and a 30-40 m thick, intensively oxidized and leached ignimbrite layer (Figs. 3, 11). The latter is best preserved for about 100 m along the southern slope of the Bonanza valley, where it is limited to the west by NNE oriented normal faulting. The high original permeability of these rocks provided by pumice

clasts in the ignimbrite (Sillitoe¹) localized hydrothermal alteration and destroyed original textures. As a result of extreme hypogene leaching, the ignimbrite underwent intense, pervasive silicification and associated alunization to leave only a highly porous skeletal texture (vuggy, residual silica). Replacement quartz is mainly chalcedonic, intergrown with alunite and disseminated jarosite and hematite.

The silicified NNE-oriented vein-like replacement structures, 5-15 m wide, pinch and swell but are traceable over a strike length of up to 500 m. The contact between silicified and non-silicified rock is generally sharp. In places, it is marked by a narrow



FIG. 11. General view of the Arqueros area, looking south. The dark-brown outcrops correspond to a highly silicified-alunitized ignimbrite layer with Ag mineralization. Several sub-vertical silicified Au-bearing veins are seen cutting through the ignimbrite.

zone (0.1-0.5 m) of fine-grained, light-gray silica; elsewhere, small, elongate hydrothermally brecciated zones with a similar light-gray silica matrix are present.

The inner zones of the silicified structures generally contain voids where feldspars and pumice fragments have been leached out and locally filled by an advanced argillic assemblage: kaolinite, alunite, limonite, and jarosite, in a groundmass of cryptocrystalline silica intergrown with alunite, barite and jarosite. Some structures show strongly fractured central suture zones (0.5-1.0 m) carrying abundant jarosite and local scorodite.

On either side of the vuggy silica zone is a zone of alunite. The alunite close to the vuggy silica completely replaces the tuff. Progressively out of the vuggy silica zone, alunite replaces mainly feldspar phenocrysts and farther out changes to kaolinite.

This hydrothermal alunite from the altered Arqueros ignimbrite and from Huantajaya silica veins yielded K-Ar ages of 23.2 ± 0.7 and 20.7 ± 0.7 Ma, respectively (Sillitoe *et al.*, in press).

MINERALIZATION

Attention was focused originally at Arqueros on two E-W striking Ag anomalies on both sides of the Bonanza valley and separated by a small, weak Au anomaly.

As noted above, Ag mineralization is mainly stratabound, associated with a subhorizontal unwelded ignimbrite, whereas Au-(Ag) mineralization is present in NNE-striking replacement, vein-type silicified structures. Stratabound Ag mineralization was explored by diamond drilling whereas Au-bearing

silicified structures were investigated by two underground levels separated by a vertical distance of 50 m.

Both stratabound and vein-like Ag-Au mineralization are almost completely oxidized and leached to 70 m beneath the Bonanza valley. Three Ag-bearing minerals have been identified: argentojarosite, electrum and native Ag. Argentojarosite is most common and is generally disseminated in jarosite. Electrum is present as tiny free grains and native Ag occurs as 5 micron grains with botroidal textures surrounded by limonite, jarosite, or silicate gangue.

Sulfide remnants in the oxidized zone are present as finely disseminated pyrite with subordinate amounts of chalcopyrite, completely surrounded by silica.

The silicified structures at surface carry Au values of 1-3 g/t, increasing to 10 g/t Au at shallow depths (20-40 m beneath surface) as found in the upper (4,058 m) underground level. Downwards, Au grades diminish and tend to disappear near the top of the

sulfide zone in the lower (4,000 m) underground level. Silver contents are on the order of 15-20 g/t, although isolated and sporadic high values, up to 90 g/t are obtained. The Ag/Au ratio in Arqueros veins ranges typically between 0.1 and 10. Taking into account that underground Ag values are generally an order of magnitude lower than in outcrops, it is thought that Ag (and silica?) was enriched at surface in the leached capping.

Lead contents range generally from 0.02% to 0.15% and follow closely the outlines of the silicified structures and the Au distribution; however higher Pb contents tend to occur near the outer margins of the silicified structures. No significant Bi or Sb anomalies are present, but relatively high Hg (5-10 ppm) is recorded at surface.

Silver values in the ignimbrite range typically from 20-100 g/t Ag, although a uniformly mineralized volume of rock has not been defined.

DISCUSSION

The Esperanza precious-metal prospect is interpreted to be related genetically to a largely concealed pre-mineralization dacite porphyry flow-dome complex, which crops out locally in the northern part of Huantajaya hill (Sillitoe²). Precious-metal-bearing breccias and veins were probably generated in a hydrothermal system related to the domes. Fracturing provided permeability for the hydrothermal fluids that caused pervasive alteration and metal introduction.

Hydrothermal brecciation is considered to be caused by magmatically heated meteoric waters (phreatic breccias), probably as a result of fluid overpressures generated by intermittent self-sealing of the system through pervasive silicification and multiple events of explosive boiling. The structural control on the emplacement of the Chimberos orebody strongly support this brecciation mechanism.

Deposition of sulfides was probably initiated during hydrothermal alteration. At least 5 volume percent of pyrite, along with subordinate amounts of Ag-bearing sulfides were introduced in the breccias and mantos as interpreted from the amount of transported limonite present at both Chimberos and Arqueros (Sillitoe²). The relatively high content of Pb in the deeper central portions of the Chimberos orebody (up to 1.3%)

implies the original presence of galena, in which Ag may have been present in solid solution. The unknown Ag-Sb-Bi-Pb compound detected in Chimberos ore may reflect substitution of Pb by Ag-Sb-Bi in the galena lattice as at Real de Angeles, Zacatecas, México (Pearson *et al.*, 1988).

The fine-grained size of sulfide remnants, as well as the presence of chalcedonic silica suggest rapid precipitation from transporting fluids due to abrupt decreases in temperature and pressure. In contrast to disseminated Ag mineralization at Chimberos, Au is present in steep tabular bodies at Chimberos, Arqueros and Huantajaya, which lack Sb and Bi. The textural characteristics of vein fill and vein breccias indicate that Au metallization followed fracturing, probably as a late-stage event. Complexities of this kind, involving repeated fracturing events and passage of dissimilar fluids are probably commonplace during the evolution of epithermal vein systems (Sawkins, 1988).

Progressive oxidation and Ag enrichment of the Chimberos breccia during Middle Miocene(?) lowering of the water table was probably favored by the relatively high original pyrite content of the rock. In contrast, only supergene Au mobilization is thought to have taken place at Esperanza.

In common with upper parts of many oxidized Ag deposits elsewhere (e.g. Wonder, Tonopah; Boyle, 1968), at Chimberos cerargyrite is the predominant mineral giving way downward to argentojarosite. The predominance of cerargyrite over native Ag in the oxidized zone is ascribed to high chloride ion activity in the local groundwater along with the stability of silver chloride complexes at low temperatures (Sangameswar and Barnes, 1983).

Silver (and Au) mineralization is restricted to a limited vertical interval, from about 4,000 to 4,200 m, which transects the stratigraphy of the area and may be observed at other similar Au-Ag deposits in the region (e.g. La Coipa; Rivera, 1988; Oviedo *et al.*, in press). Within this vertical interval, mineralogic and analytical data point to a metal zoning involving, at Chimberos, an upward progression from Pb-rich to Ag-rich limonite mineralization and, at the shallowest levels to a barren opaline-chalcedonic silica horizon which probably represents the paleowater table. The 20-40-fold decrease in Pb content towards the upper Ag-enriched zone, suggests a hypogene zoning rather than supergene enrichment or transport because widespread supergene leaching and downward migration of Pb is unlikely (Sillitoe²).

After the alteration and mineralization processes waned, a dacite porphyry dome was emplaced in the Potosí-Huantajaya area. The emplacement of this post-mineralization dome is probably responsible for the disruption of the Au-Ag bearing silicified veins at Huantajaya.

The geochemical suite As, Sb, Bi, Ba and Hg accompanying Au-Ag mineralization at Esperanza, the low-temperature character of the replacement silica (opal, chalcedony) and the sulfur-rich alteration mineralogy, suggest a high level epithermal system (Buchanan, 1981; Beger and Eimon, 1983), probably generated in a paleogeothermal system of high-sulfidation (Bonham, 1986) or acid-sulfatetype (Heald *et al.*, 1987).

Although the Middle-Tertiary paleosurface is

absent and not characterized by strong precious-metal enrichment, the erosion level at Esperanza is considered to be relatively shallow, probably not more than 200 m beneath the paleosurface. Evidence for this estimate includes the subhorizontal rather than inward-dipping flow banding in the northern part of the post-mineralization dome, which suggests that the upper flat-surface of the dome is being approached, and the relatively thin, subhorizontal chalcedonic replacement zones, which are believed to represent paleowater tables (Sillitoe²).

COMPARISON WITH OTHER AG-AU DEPOSITS IN THE AREA

In the overall Esperanza area (Fig. 1), two epithermal disseminated precious-metal deposits are being mined: the Eocene-Oligocene El Hueso Au deposit (Brook *et al.*, 1987; Colley *et al.*, 1989) and the volcanic- and sediment-hosted Oligocene-Miocene La Coipa Ag-Au deposit (Rivera, 1988; Sillitoe *et al.*, in press; Oviedo *et al.*, in press).

According to published descriptions and personal observations, La Coipa deposit also corresponds to an acid-sulphate or high-sulfidation epithermal system, which shares remarkable similarities with Esperanza in terms of geological-structural control of mineralization, hydrothermal alteration patterns, Ag-Au metallization timing, and ore mineralogy.

Besides the obvious difference in mineralized rock volumes between these deposits (La Coipa hosts an aggregated 61.2 million tons orebody averaging 1.37 g/t Au and 77 g/t Ag, Oviedo *et al.*, in press), a distinctive Au-rich (up to 70 g/t Au) multi-directional array of alunite veinlets cutting Triassic shale occurs locally at the La Coipa orebody. Considering that the Triassic basement beneath the volcanic cover has not been systematically explored at Esperanza, interesting prospecting possibilities for disseminated Au mineralization at the Santa Rosa and Potosí areas are envisaged.

ACKNOWLEDGEMENTS

Several geologists worked with the author during field work at Esperanza. E. Viteri (Exploration Manager), J. Betzhold, M. Sánchez, D. Pacci, J. Rodríguez, A. Rojas, R. Albornoz, A. Heresman, and R.H. Sillitoe, who carried out diverse geological studies in the area and from which the author benefited.

Special thanks are given to R.A. Lyall, Anglo American Consulting Geologist for South America, who made major contributions to the organization and development of exploration in the Maricunga belt and encouraged the submitting of the manuscript.

Helpful comments and discussions that improved

the manuscript were provided by N. Lindsay, C. Cunningham, W. Hildreth, V. Makshev and R.H. Sillitoe. V. Garrido and M. Maeztu provided timely

and careful drafting and typing services.

Publication of this paper is authorized by Minera Anglo American Chile Ltda.

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