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GEOLOGY OF THE UJINA AND ROSARIO COPPER PORPHYRY DEPOSITS, COLLAHUASI DISTRICT, CHILE

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Abstract - Several different types of deposits are found within the Collahuasi district, but two copper porphyries are notable for their magnitude: Ujina and Rosario. The differences in the level of erosion and degree of pre- and post-mineralization faulting between the two deposits has resulted in a wide variation in size and morphology of the respective secondary enrichment zones and the characteristics of the subjacent primary ore.

The Ujina porphyry is located 7 km to the east of Rosario and is contained within a distinct hydrothermal system. One important characteristic is the presence of a sub horizontal body of secondary enrichment, a fact that could explain why the column of primary mineralization has undergone a favourable enrichment process due to the absence of major mineralization controlling faults and a deeper level of erosion (4200 m above sea level) with respect to that in the Rosario deposit. Other aspects, such as the virtual absence of copper veins, the lower copper ore grades and amounts of pyrite in the primary ore that underlie the enrichment body, and the distribution of the hypogene alteration facies could also be explained by erosion that has exposed the deeper levels of the Ujina porphyry system.

The Rosario porphyry encompasses a 1 km2 area within a 5 km radius hydrothermal alteration zone. The Rosario system also includes bornite – chalcopyrite (Bn–Cp) veins which crosscut the porphyry mineralization. The deposit is structurally complex due to the intense post-mineralization faulting. The level of erosion (down to 4650 m above sea level) exposes low grade hypogene mineralisation with propylitic alteration. The copper ore grade in hypogene mineralised zones and the Bn/Cp ratio increase with depth, while the pyrite content decreases. The morphological complexity and the low volume of enrichment material is the result of structural control on the supergene processes.

Background

The mining history of the district, compiled by Marquardt (1984), began with the Incas, whose activities are evidenced by copper tools and remains of small smelter sites. It was not until 1880 when commercial exploitation of the high grade veins in the sectors of Poderosa and La Grande began. The production of these areas lasted until 1930, reaching a total of 300 000 t of 25% average grade copper mineral, 180 g/t of silver and 2 g/t of gold. Mining activity resumed in 1977 with modern exploration programs.

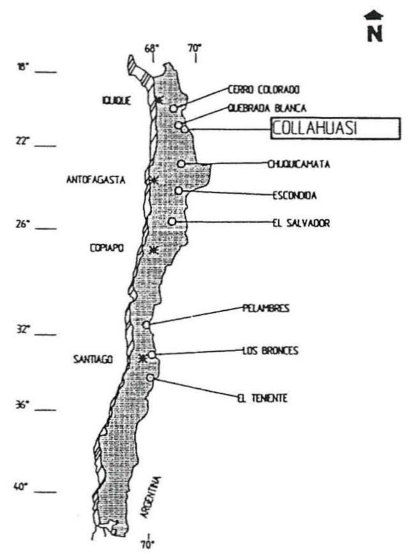


Fig. 1 - Location Map

Exploration in the late 1970's and early 1980's allowed for the consolidation of the Quebrada Blanca deposit, definition of the Rosario deposit, recognition of the mineralised sections around the Rosario porphyry system and preliminary studies of the Ujina area (Hunt et al., 1983).

In September of 1991, after an intense exploration program, which included detailed geologic mapping, geochemistry, satellite image analysis and geophysical studies, the Ujina porphyry deposit, with its important sub horizontal secondary enrichment, was confirmed and described by Dick et al., (1993). After several years, a feasibility study for the exploitation of the Ujina, Rosario and Huinquintipa deposits concluded in July of 1995. Currently, the Compañia Minera Doña Inés de Collahuasi is owned by Minorco Limited (44%), Falconbridge (44%) and a Japanese consortium headed by Mitsui (12%).

Introduction

The Collahuasi district is located 180 km to the southeast of Iquique in the Altiplano of the First Region of northern Chile at an elevation which varies from 4300 to 4800 m above mean sea level. It falls within a north-south trending belt of Tertiary copper porphyries which follow the north-south trend of the Andes mountain range (Figure 1).

The district extends for 30 km in a north-south direction and 40 km in an east-west direction, and is located within a horst of Mesozoic and Paleozoic rocks. This structural feature continues for 200 km to the south and includes the northern extension of the Copper porphyry belt, which also incorporates the world class Chuquicamata and El Abra districts. The block was raised in the Upper Tertiary following the deposition of Tertiary ignimbrites and gravels with an estimated age of 10 to 15 Ma (Figure 2).

A NNW trending mega-fault, known as the West fissure, delineates the western flank of the district, separating Jurassic marine and continental sediments to the west from Permo-Triassic volcanics and granitic batholiths to the east (Figure 2). However, the fact that a 4.3 Ma ignimbrite near Quebrada Blanca has not been faulted indicates that this fault has not been active since the horst was uplifted (Munchmeyer, 1984). A second north-south trending principal fault, the Loa fault, forms the eastern border of the horst in the vicinity of the Salar Michincha. This discontinuity also represents the western border of a graben filled with Upper Tertiary and Quaternary volcano clastic deposits and ignimbrites. The fault trace in the area of Michincha is correlated with structures identified in geophysical studies related to hydro-geologic exploration (Hargis and Montgomery, 1982).

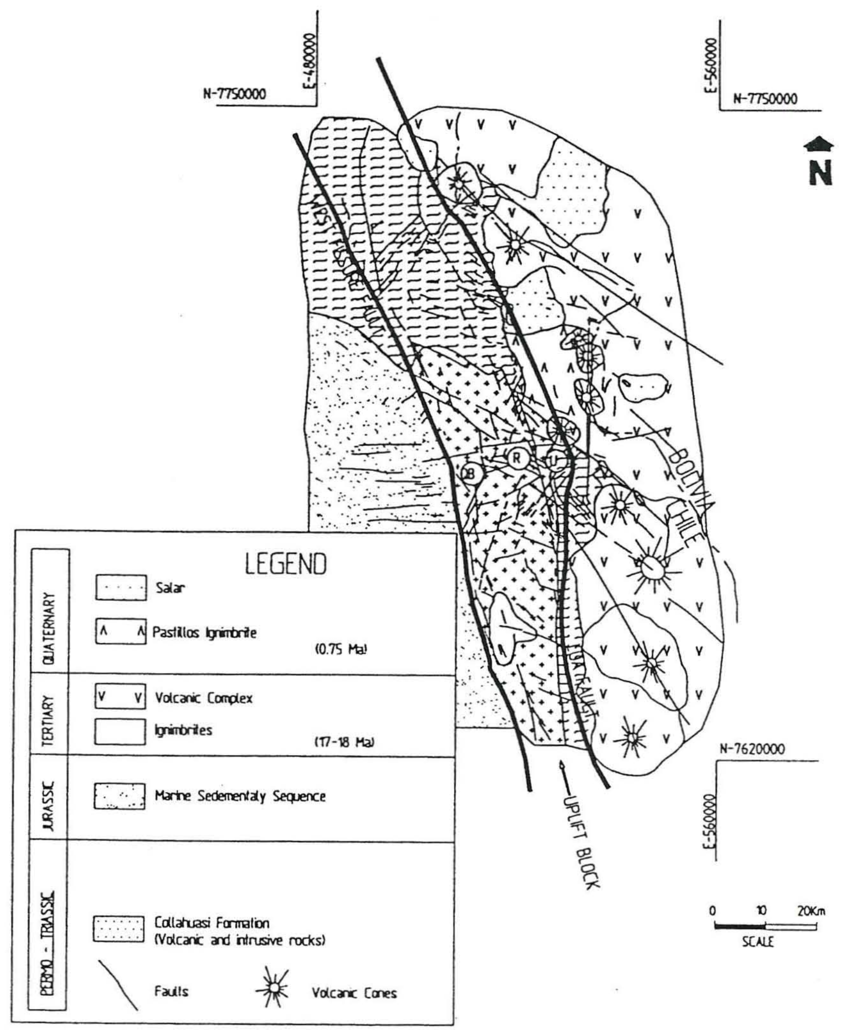
Although insufficient information is available to improve the knowledge of the structural history of the district, sinistral movements in these two principal faults have resulted in the development of conjugated NW and NE fault systems associated with the Tertiary intrusive activity and the formation of the Quebrada Blanca, Rosario and Ujina copper porphyries. Tertiary andesitic strato-volcanos lie on the eastern margin of the Loa fault.

The district is characterised by the presence of two hydrothermal systems, each of which contains a copper porphyry deposit (Rosario and Ujina), and a variety of copper (Ag-As-Au) vein systems linked both spatially and genetically to the Rosario porphyry (Figure 3). Processes subsequent to the secondary enrichment have formed bodies of oxides and secondary sulphides over the two porphyries.

The La Grande deposit, still being explored, is located NW of the hill of the same name and comprises a system of high grade copper massive sulfide veins, around which secondary enrichment halos up to 50 m developed (Bisso and Gonzáles, 1993).

An exotic copper oxide deposit, named Huinquintipa, formed when copper oxides were deposited as cement in gravels in palaeo-channels with headwaters in the Rosario sector. A fourth porphyry system, Profunda, developed directly to the east of Ujina, and is covered with approximately 400 m of post-mineralization Tertiary ignimbrites.

Fig. 2 - Simplified Regional Geology



District Geology

The basement of the region between the Salar Michincha (salt flat) and the West fault consists of Paleozoic granitic plutons of the Collahuasi Complex (Vergara, 1978). The intrusives vary in composition from diorite to quartz monzonite. The majority date to the Permian (231 to 262 Ma).

These Permian plutons cut through a volcano-sedimentary sequence with andesitic to rhyolitic compositions and approximately 4 km in width, informally included in the Collahuasi Formation. The volcanics are composed of two or more cycles of andesite flows with intercalations of sediments.

The lower part of the volcanic sequence is locally termed the La Grande Unit and has been well defined by drill holes in the areas of Quebrada Blanca and Rosario. This unit consists of an alternating sequence of at least 1700 m of rhyolites, dacites and andesites with intercalations of volcaniclastics and limestones, which have been assigned to the Condor – Capella Unit. The volcanic rocks are deformed by large open folds of regional scale.

The age of the volcanics has been difficult to establish. The fact that they underlie an unconformity at the base of the Jurassic sedimentary package indicates a pre-Jurassic (Permo-Triassic) age. To the south of Collahuasi a Permo-Triassic granodiorite intrudes the base of the same volcanic sequence and appears to confirm the estimated pre-Jurassic age. To the north of Quebrada Huinquintipa a granodiorite, dated as 231 Ma, also intrudes the volcanics. In Rosario, this same granodiorite, termed the Collahuasi porphyry, has been dated as 110 Ma, which indicates a rejuvenation event as a result of more recent intrusive events in the region.

Tertiary Intrusion and Faulting. The structural arrangement of the district is dominated by NNW, NE and north-south trending Tertiary fault systems. The most important NNW faults are the aforementioned West and Loa faults, while other sub parallel faults and fracture zones are observed near the Rosario and Ujina deposits. The direction of movement along these systems is predominantly left-lateral (sinistral), with estimated maximum displacements of 1 to 1.5 km (Munchmeyer et al., 1984). Vertical movements along the Loa fault have formed a basin now filled with Miocene to Quaternary ignimbrites and volcanic sediments. The ignimbrites, which are deposited immediately to the east of Ujina, reach a thickness of 400 m and geophysical information indicate similar thicknesses for the packages of ignimbrites to the north of the Salar Michincha.

Northwest and northeast trending faults, identified using satellite images and aerial magnetics, have proven to be important controls of mineralization in the district, particularly in Rosario where the NW trending faults have controlled the development of vein mineralization and possibly intrusive activity. Both normal and reverse movements, pre and post-mineralization, have been interpreted in the NW trending faults in the Rosario area (Gallardo, 1991). North-south structures host the Monctezuma (Ag/Mn) and La Grande (Cu/Ag) vein systems, and separate the Ujina and Rosario hydrothermal systems.

The intrusive activity in the Collahuasi district has been partially documented with K/Ar dating results reported in Munchmeyer et al., (1984). Oligocene intrusions are associated with the Rosario and Ujina copper porphyries, like many other similar deposits in Chile. Within the district, these rocks are granodioritic to quartz-monzonitic, and because of their similar mineralogic compositions and textures, it is suggested that they could originate from the same, deep seated parent magma. Dating of the Rosario porphyry indicates an Oligocene age (34.2 ± 1.5 Ma) for the mineralising event and emplacement of the porphyry.

More recent $^{40}Ar/^{39}Ar$ dating of the Rosario porphyry indicates an emplacement event at 33.12 ± 0.10 Ma (Munizaga, 1995) and 32.8 ± 0.4 Ma (Clark, A. et al., 1997), while that of Ujina was determined to be 34.57 ± 0.13 Ma. A subsequent intrusive, termed the Inca porphyry, with an age of 34.23 ± 0.13 Ma, intrudes the Ujina porphyry, representing a post-mineralisation intrusive event related to the same magma source. The Ujina dates are under review since the new district information suggest a discrete eastward migration in the early Oligocene.

Late Tertiary and Quaternary Volcanism and Faulting - The region was subjected to intense uplift and erosion in the Oligocene-Miocene, even though movements along the West fault apparently had ceased by the end of the Tertiary. The tectonic activity continued, as can be appreciated in the area of the Loa fault, where large volumes of Miocene-Holocene volcanic and ignimbritic sequences were deposited contemporaneously with the development of a basin in the eastern sector of the Collahuasi District. Continuous movements along faults related to the Loa fault is inferred from stratigraphic evidence in the Coposa Basin. It appears that the deposition of two separate Miocene ignimbrites, known from the area, was coincident with movements along the Loa fault, where subsidence in the eastern sector formed the Coposa, Michincha and Alconcha basins. The Huasco ignimbrite (14-19 Ma) covers more than 1800 km^2 to the north, including the western flank of the Coposa basin. The Ujina ignimbrite (9.4 Ma) extends from the eastern part of the area of Ujina to the headwaters of Loa River to the south.

The most recent phase of Andean volcanism involves the development of strato-volcanos that form the frontier between Bolivia and Chile. They are of andesitic to dacitic composition and many show evidence of historic explosive activity (Gardeweg, 1991).

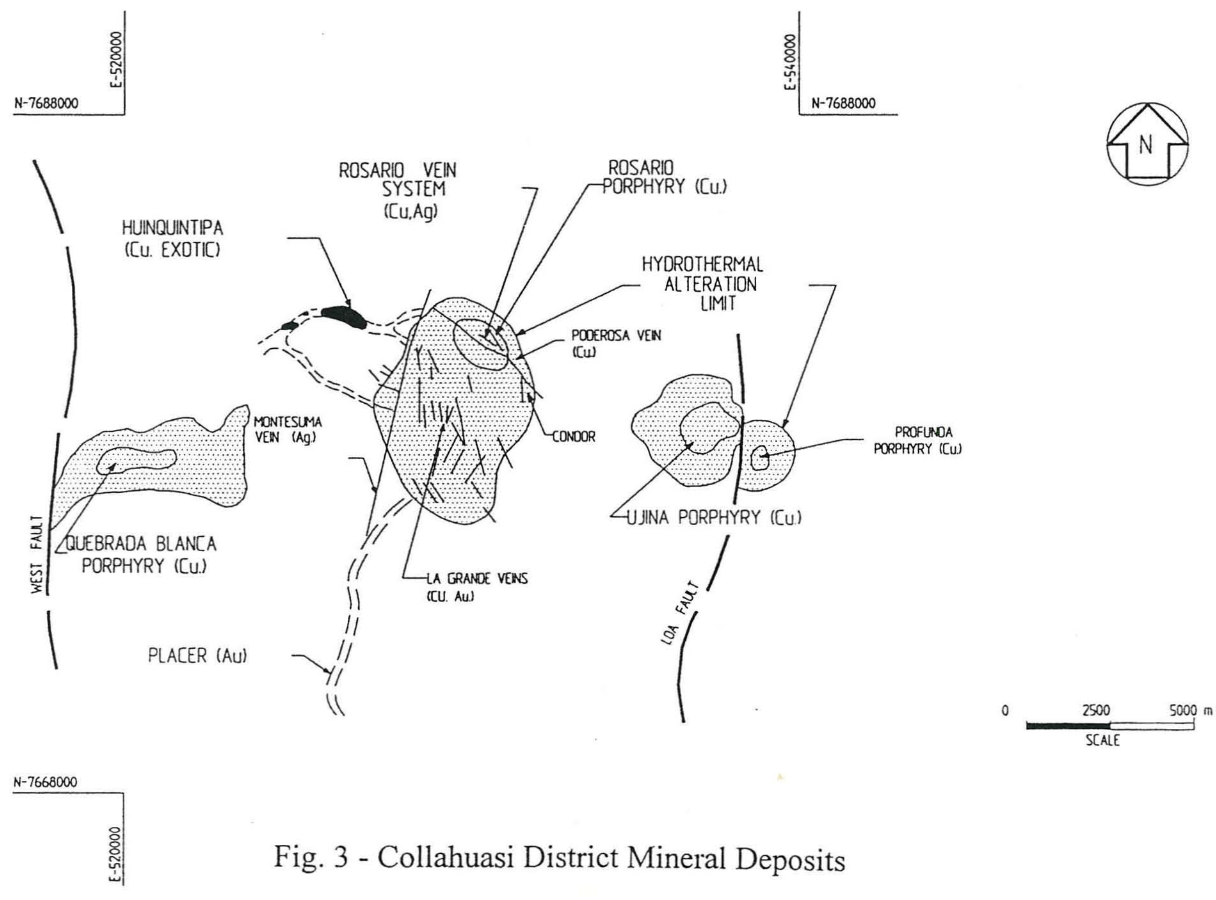


Fig. 3 - Collahuasi District Mineral Deposits

Irruputuncu, Olca and Auncanquilcha are three volcanic centres which still exhibit fumerolic activity. The Pastillos ignimbrite (0.75 Ma) is 200 m thick and overlies the Ujina Ignimbrite. It is composed of ash deposits, principally pumice, and is capped by lava flows from the Irruputuncu volcano.

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Economic Geology of the Collahuasi District - The principal mineralization centres of the Collahuasi district are the Rosario and Ujina hydrothermal systems (Figure 3). These deposits are characterised and classified as copper porphyries. They present large, highly fractured and hydrothermally altered zones, which have affected several different types of host rock. The more economically important component is the copper, and in lesser proportions, molybdenum and silver. The mineralization is distributed along fractures, in micro-veins and disseminated throughout the host rock. Exotic copper mineralization occurs as cement in gravels, and in the remnants of the Upper Tertiary palaeo-channels down slope from the Rosario and Ujina deposits.

Geology of the Ujina Deposit

The Ujina deposit is located 7 m to the east of Rosario, within an independent hydrothermal system, as determined by geophysical anomalies. It constitutes a copper porphyry, a large part of which has been eroded, with its potassic alteration zones directly below the palaeo-surface of erosion. One zone of low resistivity occupies the centre of the system and coincides with the part of the system that is richest in copper. Detailed exploration, performed between 1992 and 1994, consisted of 331 surface drill holes on a 70 m grid, covering an area of 1.8 x 1.5 km, and underground workings consisting of an excavation of a shaft 252 m in depth and 423 m of underground workings on three levels.

Host Rock Geology - The Ujina deposit is a classic copper porphyry type deposit, according to its mineralization, alteration and zonation characteristics. The advanced level of erosion, along with the favourable tectonics, permitted the development of a thick, continuous zone of secondary enrichment.

The surface geology is dominated by the Ujina ignimbrite and recent colluvial deposits, both of which combined cover more than 90% of the deposit. The ignimbrite varies in thickness from 0 to 110 m, thickening to the east. The rhyolites of the La Grande Unit outcrop west of the deposit and are characterised by their highly fractured and leached nature and a moderate alteration, exhibiting iron oxides stains on fracture surfaces. Flows and breccias of porphyritic andesite rich in plagioclase dip slightly to the east. The local stratigraphy, shown in figure 4, is simple, with a sequence of andesites overlain by rhyolites, and a unit of sedimentary breccias, which only appears in the extreme eastern part of the deposit, overlain unconformably by the units above. The Ujina porphyry, a granodioritic intrusion rich in feldspar phenocrysts (Ip, 1995), intrudes these units, generating abundant roof pendants and

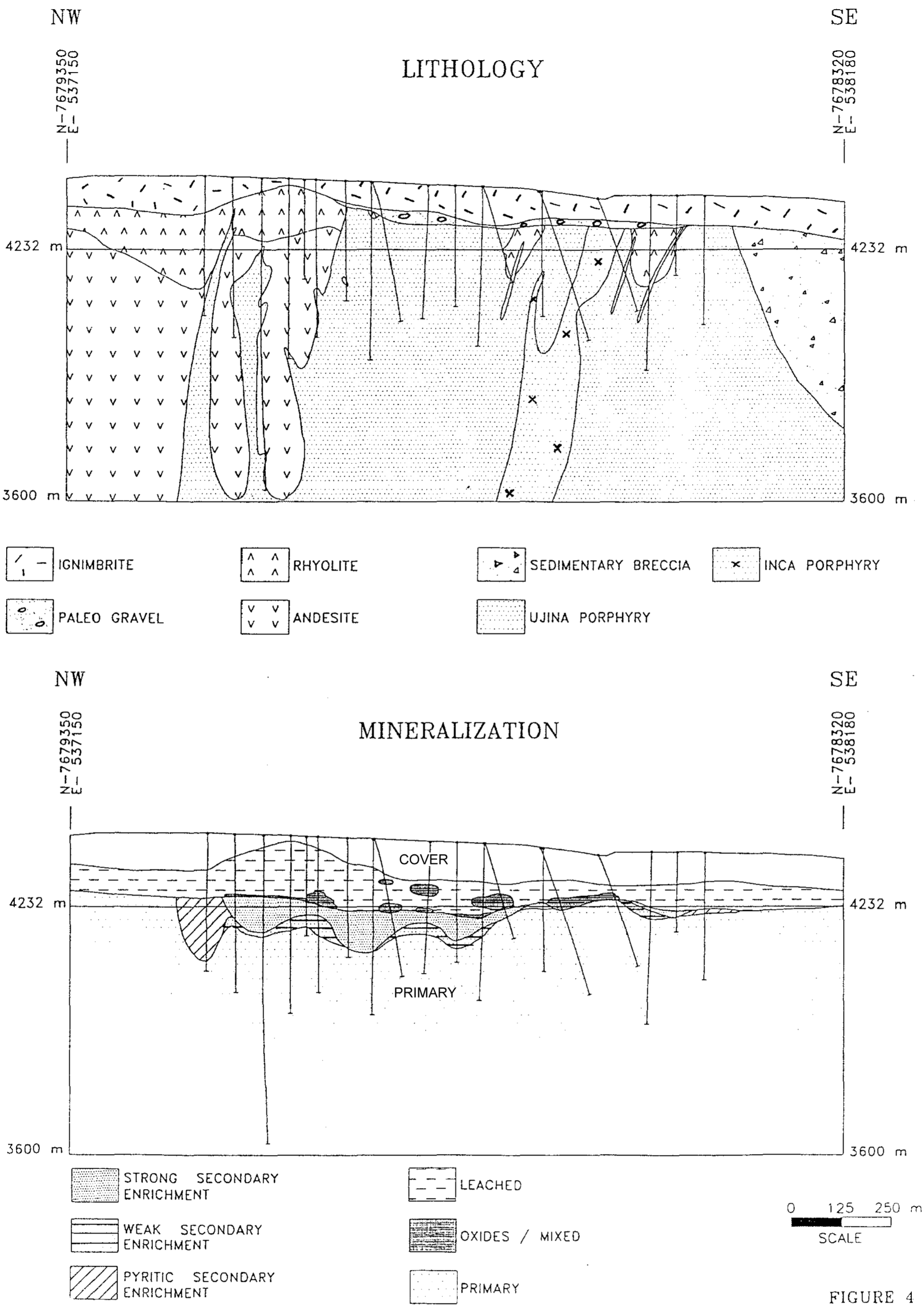


Fig. 4 - Ujina Deposit, Section 126 NE (looking NE)

xenoliths in the central areas and borders of the intrusion. The western contact between the volcanic sequence and the Ujina porphyry is sub-vertical and is marked by locally intense brecciation and abundant apophyses of the intrusion. The porphyry is oriented in a generally NE direction, possibly related to NE structural control during its emplacement, and is volumetrically the most important host rock of the mineralization.

The Ujina porphyry is intruded by a suite of fine grained dykes, termed the Inca porphyry, and are oriented to the NE, except in the western sector of the deposit where interpretations suggest a W to NW strike. These are compositionally similar to the Ujina porphyry, but are finer grained and possess a higher content of quartz eyes and amphiboles. A chloritic alteration superimposed over an albitisation imparts a green tone to the generally fresh appearance of these rocks. The dykes of Inca porphyry are interpreted as the latest stage magmatic event which formed the mineralised porphyries of the district. There is weak primary mineralization and practically no secondary enrichment within the Inca porphyry, with exception of copper oxides in areas close to the surface. The dykes are important in that they are not mineralised, and thus break the continuity of the secondary enrichment zone.

Igneous breccias occur along the margins of the Inca Porphyry dykes. When these breccias developed is not completely understood, however, their matrix is similar to that of the Inca porphyry and they contain clasts of the porphyry, which indicates that they formed contemporaneously or soon after the dykes. The breccias may contain high grade chalcopyrite and bornite mineralization, characterising a late phase of bornite that followed the primary mineralization.

The Permo-Triassic volcanic stratigraphy, the Ujina porphyry and the dykes of Inca porphyry were uplifted progressively, forming at some point, a palaeo-surface which was subsequently covered with the Ujina ignimbrite. The contact is marked by a poorly consolidated palaeo-gravel, which locally varies in thickness between 0 and 20 m. The inferred direction of transport of the material is SW to NE.

Hypogene Mineralization - Mineralogical studies of Ujina have revealed a classic copper porphyry zonation pattern. A centre with low sulfide content and chalcopyrite and bornite mineralization grades outwards to a chalcopyrite-pyrite zone, which finally yields to a low grade pyrite (chalcopyrite) zone (De Beer and Dick, 1994).

Chalcopyrite is the principal copper mineral, while bornite only occurs in the central part of the low pyrite zone. The mineralization typically occurs in veins, fracture planes and as disseminations in the matrix of the host rock. The average grade of the primary copper mineralization in Ujina to a cutoff grade of 0.4% is 0.66% Cu. High grade primary mineralization follows a concentric distribution pattern, coincident with the borders of the Ujina porphyry, which is especially important in the western part of the deposit, near the contact between the porphyry and the andesites. The grades vary between 0.8% and 1.0% Cu. The actual width of this concentric zone has not been defined, but seems to vary between 100 and 200 m, with a sub-vertical inclination. This ring is reflected also in the subsequent distribution of supergene enrichment (Figure 5).

Hypogene Alteration - The pattern of primary alteration in Ujina consists of an arrangement of concentric zones with a potassic core (zone of potassic feldspar) that grades outwards to a potassic zone rich in biotite and poor in potassic feldspar, then to a quartz-sericitic phase coincident with the high grade primary ore. This in turn, gradually becomes an outer zone, or propylitic halo, with low grade copper and barren rock.

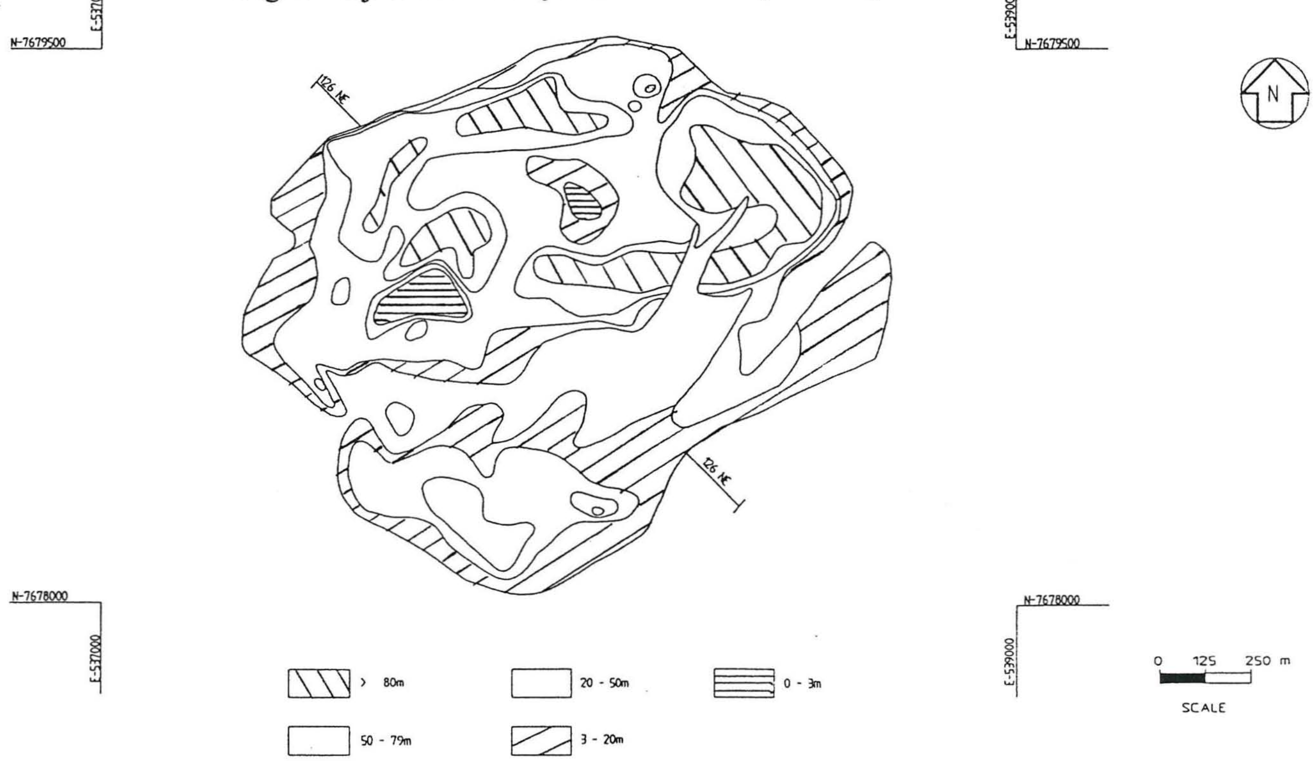
A zone of mixed sericite and chlorite is common in this deposit. As a general rule, the chlorite content increases towards the periphery of the deposit, while the amount of sericite decreases correspondingly, except in the rhyolites, which maintain their quartz-sericitic alteration. In the sedimentary breccia, the chlorite appears associated with a propylitic alteration rich in calcite.

Fractures and Faults - In the area of the Ujina deposit there are variable fracture patterns associated with the different lithologies. Faults with large movements (more than 10 m) have not been observed. Structures which strike north-south, NW and NE are the most common in Ujina, and control the emplacement of late stage veins with chalcopyrite, tennantite and enargite fillings. These particular structures have not been observed to continue upwards into the ignimbrites that cover the deposit, even though there is a similarity in the dominant strike directions.

Supergene Alteration and Mineralization - Moderate to intense argillic zones are associated with the zone of secondary enrichment. In order of decreasing abundance, the principal varieties of clay are, sericite, kaolinite and montmorillonite. The argillic alteration predominates in the leached zones, except in the rhyolites. The quartz-sericitic alteration is associated with the development of type D veins, which tend to occur with such high frequency per meter as to completely obliterate the original rock.

These processes are more pronounced in Ujina than in Rosario, due to the deep erosion and penetrative fracturing which permitted meteoric waters to dissolve and re-precipitate the copper in successive periods of tectonic uplift. This has produced the development of a supergene enrichment zone of high grade copper, approximately sub parallel to the present topography, with sectors of mineralization of lesser grade where the dykes of Inca porphyry appear.

Fig. 5 - Ujina Secondary Enrichment Isopach Map



Low grade oxides are irregularly distributed within the leached zone, below the cover of ignimbrites and palaeo-gravels. This facies is visually similar to the leached zone, but where it is spatially related to the Inca porphyry dykes, the copper grades reach 0.6%. It is characterised by the occurrence of oxides absorbed onto clays (chrysocolla) and in aggregate forms with manganese (copper pitch and copper wad). The oxides occur at the base of the leached cap and average 5 to 10 m in thickness. This facies is preferentially developed in the central-western sector of the deposit, coinciding with the low pyrite zone. The principal oxidised mineral is chrysocolla, accompanied by cuprite and malachite in secondary form.

The mixed facies represents a zone located between the secondary enrichment and the oxides, in which the oxides and sulphides coexist. Volumetrically, this zone is small and is approximately 5 m in width. It is characterised by the presence of chalcocite and chrysocolla with the appearance of native copper and cuprite in fractures and disseminations near the contact with the enriched zone.

The secondary enrichment zone has been divided into three categories depending on the relative quantity of secondary copper sulphides (chalcocite-covellite) versus primary copper sulphides (chalcopyrite-bornite). In this manner, the strong secondary enrichment is that which contains over 75% Cc and Cv, the weak secondary enrichment is that which contains between 75% and 25% Cc and Cv, and primary is all that contains less than 25% secondary copper sulphides. The contact between the two enrichment facies is usually quite irregular and is marked by a rapid fall in copper grade (refer to Figure 4).

The secondary enrichment over pyrite is another category, which is characterised by the development of chalcocite coatings on pyrite. This phase forms preferentially in the pyritic halo of the deposit where pyrite is basically the only sulfide present. Because of this, the copper grades in this zone are usually less than 0.4%, never exceeding 1.0% Cu.

Geology of the Rosario Deposit.

The Rosario deposit constitutes a moderately preserved copper porphyry, in which the potassic zones have not been affected significantly by erosion. The area of interest of the deposit measures 2 x 1.5 km and has been investigated in detail from 259 diamond drill holes and a shaft of 273 m in depth, with 760 m of additional horizontal workings.

Host Rock Geology - The deposit is emplaced in a wide variety of rocks, which form a sequence of andesites and rhyolites in the upper part of the La Grande Unit, and volcanic sands, calcareous sediments and rhyolites of the Condor-Capella Unit. These lithologies, which are shown in Figure 6, are oriented with strikes to the NW and moderate inclinations to the NE.

The andesites vary in texture from fine-grained to very coarse-grained. The rhyolites are generally fine-grained, even though some are porphyritic with quartz eyes and flow textures. The facies changes of these units are frequent, making reliable correlations difficult.

Three intrusive events have affected the Permo-Triassic volcano-sedimentary sequence. The most important intrusion corresponds to the Collahuasi porphyry. It is characterised as a medium-grained granodiorite with variable colour from pink to tan according to the potassic feldspar content. The unit outcrops to the southeast of the Rosario deposit, a point at which it is not mineralised. The Inés porphyry, a strongly mineralised dacitic sill intrusion restricted to the area of the deposit, does not show a clear contact relationship with the

Collahuasi porphyry, but it is presumed that the former crosscuts the latter. The Inés porphyry is dark grey with few plagioclase and biotite phenocrysts, immersed in a mesostasis rich in quartz.

The Rosario porphyry is considered the youngest intrusion and would be the source of copper mineralization. It is only observed in apophysis dykes in the upper zones of the volcanic sequence, while at an approximately 400 m depth it forms a stock. It is composed of a medium grained porphyritic granodiorite with approximately 50% plagioclase and, in decreasing quantities, potassic feldspar, biotite and quartz (Ip, 1995). From drill core mapping, it is known that this intrusion clearly crosscuts the Collahuasi and Inés porphyries.

Structural System - The Rosario system is affected by various principal faults and other less significant parallel faults, all striking NW and lightly to moderately dipping to the SW, some with normal movement and others with reverse movement. The Rosario fault, the longest active structure, appears to have controlled the emplacement of the Rosario porphyry, the distribution of primary mineralization and the development of the Rosario vein system. Movement along this fault, estimated to be 120 m in a vertical sense, continued even after the hydrothermal activity ceased, truncating the Rosario vein at depth. Other important parallel faults appear along with this structure (Figure 6). The Jack Rock fault is a low angle reverse fault, which, in its hanging wall, propylitic alteration and low grade mineralization are recognised, while in its footwall, it is common to find sericitic alteration and sectors with high grade copper. Relative movement is estimated at 50 m. The Bottom fault is estimated to have 40 m of normal relative movement. The Top fault corresponds to a low angle reverse fault, which has placed a block of barren Collahuasi porphyry over the altered and mineralised units, for which a displacement of several kilometres is necessary.

Hypogene Mineralization - The mineralization facies distribution in Rosario is complex due to the intense faulting which affects the rocks of the deposit. The primary mineralization resources are by far the most important, particularly below 4400 m above sea level.

Primary copper mineralization in the form of chalcopyrite and secondary bornite appears as disseminations and veins, and is distributed in a distinctive, concentric, zonal pattern, characteristic of copper porphyries. A peripheral halo of low grade pyrite-chalcopyrite progressively changes towards the centre by increasing the chalcopyrite:pyrite ratio, until the appearance of bornite at depth. The bornite is more abundant in the surroundings of the Rosario porphyry, where it constitutes up to 50% of the total copper sulfide material. The bornite also appears to be associated with the Rosario vein system, which is related to a late stage copper mineralization along fractures associated with the formation of the Rosario fault (Dick et al., 1984).

The distribution of copper grades conserves the zonal form of the primary mineralization, with a lower grade copper in the outer pyrite rich region, increasing gradually towards the bornite rich zone in the centre. This distribution is modified by the subsequent development of veins and by the effects of supergene processes, which have improved the copper ore grades to great depths within permeable faults. Strong secondary enrichment predominates from the surface down to approximately 150 m, always following structures. A weaker enrichment reaches depths of 600 m when channelled by discontinuities (Figure 6). Molybdenum typically reaches grades of 0.02%, and silver varies between 1 and 5 ppm, with considerably higher grades in vein zones.

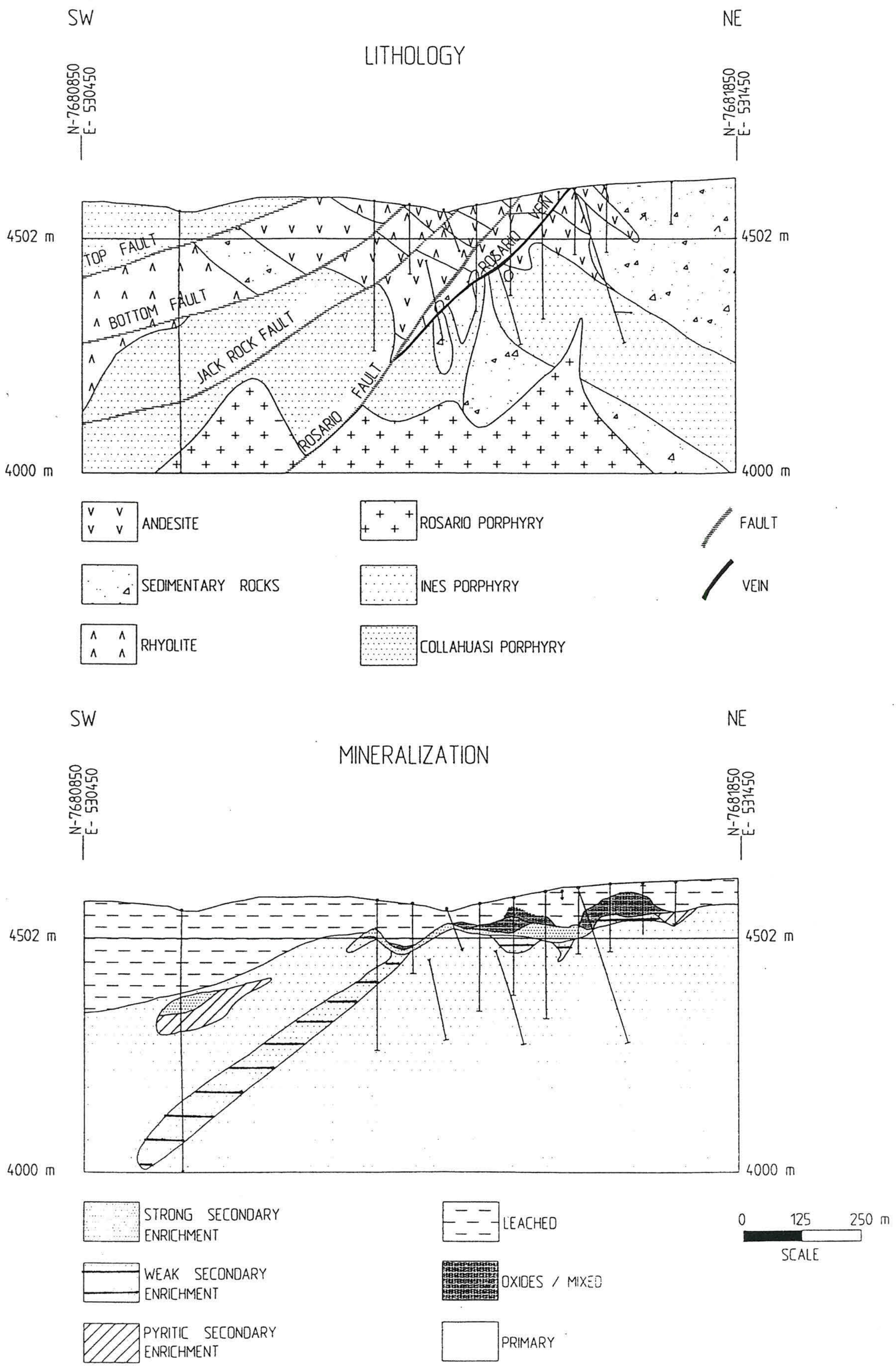


Fig. 6 - Rosario Deposit, Section 23 NE (looking NW)

Hypogene Alteration - This deposit is characterised by a practically un-modified potassic zone, while the sericitic alteration zone has been partially eroded. The potassic alteration is represented by potassic feldspar mineralization, disseminated albite and secondary biotite veins, and is associated with the initial introduction of copper to the system. Quartz-sericitic alteration is associated with the principal period of mineralization, obliterating the potassic alteration phase in its upper zones. The most intense quartz-sericitic alteration coincides with the trace of the Rosario fault and the Rosario vein system, which indicates that the hydrothermal fluids were channelled along these structures. Propylitic alteration rich in chlorite occurs along the Jack Rock fault, indicating its marginal condition with respect to the system. Skarns developed locally at the contacts between the Rosario porphyry and calcareous beds in the volcaniclastic sediments. Their mineralogy consists of diopside, garnet, epidote and amphiboles accompanied by abundant magnetite and lesser amounts of chalcopyrite and pyrite. Even though high copper grades occur in these zones, their tonnage is relative low.

The Rosario Vein System - Numerous copper veins, from 1 to 2 m wide, with NW orientation and moderate inclination to the SW, form what is known as the Rosario vein system, of which the Rosario vein-fault is the most important. This particular vein has been identified in drill holes along a stretch of more than 800 m. Its thickness varies between 1 and 15 m, dipping usually at about 45°SW, and shows irregularities in its mineralogy and copper grade. The first mineralising event in the vein corresponds to a quartz sericitic alteration stage with an introduction of pyrite and minor chalcopyrite, enargite, bornite and tennantite. In a subsequent high grade mineralization phase, large quantities of bornite were introduced with minor amounts of chalcopyrite, enargite, "grey copper" and sulphosalts (Dick et al., 1994). In the upper parts of the vein system, the primary minerals have been almost completely replaced by secondary chalcocite.

Supergene Mineralization - The leaching of the chalcopyrite and bornite by meteoric waters and the subsequent supergene enrichment of the primary mineralization developed irregular zones of copper oxides, mixed and secondary enrichment, assisted by the strong structural control that the Rosario structural system imposed.

The volcanic rocks of the leached zone are bleached and exhibit argillisation, commonly with abundant secondary iron oxides with residual chrysocolla and secondarily bronchantite mineralization. Some of these leached zones reach grades of 0.4% CuT, even though there are no visible copper oxides. These have been termed zones of "low grade oxide," which have a direct relationship with high amounts of clays. The traditional oxide zones generally have copper grades of >0.5% CuT, concentrating in reducing rocks such as andesites and volcanic sediments. The mixed mineralization is often rich in pyrite, chalcocite and covellite, as well as chrysocolla, cuprite, native copper and other copper oxides.

The secondary enrichment zone is small compared to that of Ujina, and is characterised by the presence of a high percentage of secondary chalcocite and by an irregular form due to the fact that the lower contact follows fault traces and systems of high frequency fractures. It is well defined in the NE quadrant of the deposit, where its average grade is 1.6% CuT. The weak secondary enrichment zone, by definition, consists of chalcopyrite-bornite coexisting with chalcocite and/or covellite. This zone is generally found at the margins or under the strong enrichment zone, and is well developed both in the zone located between the Rosario and Jack Rock faults, and in the vicinity of the Rosario vein system. Secondary enrichment over pyrite is poorly developed in Rosario.

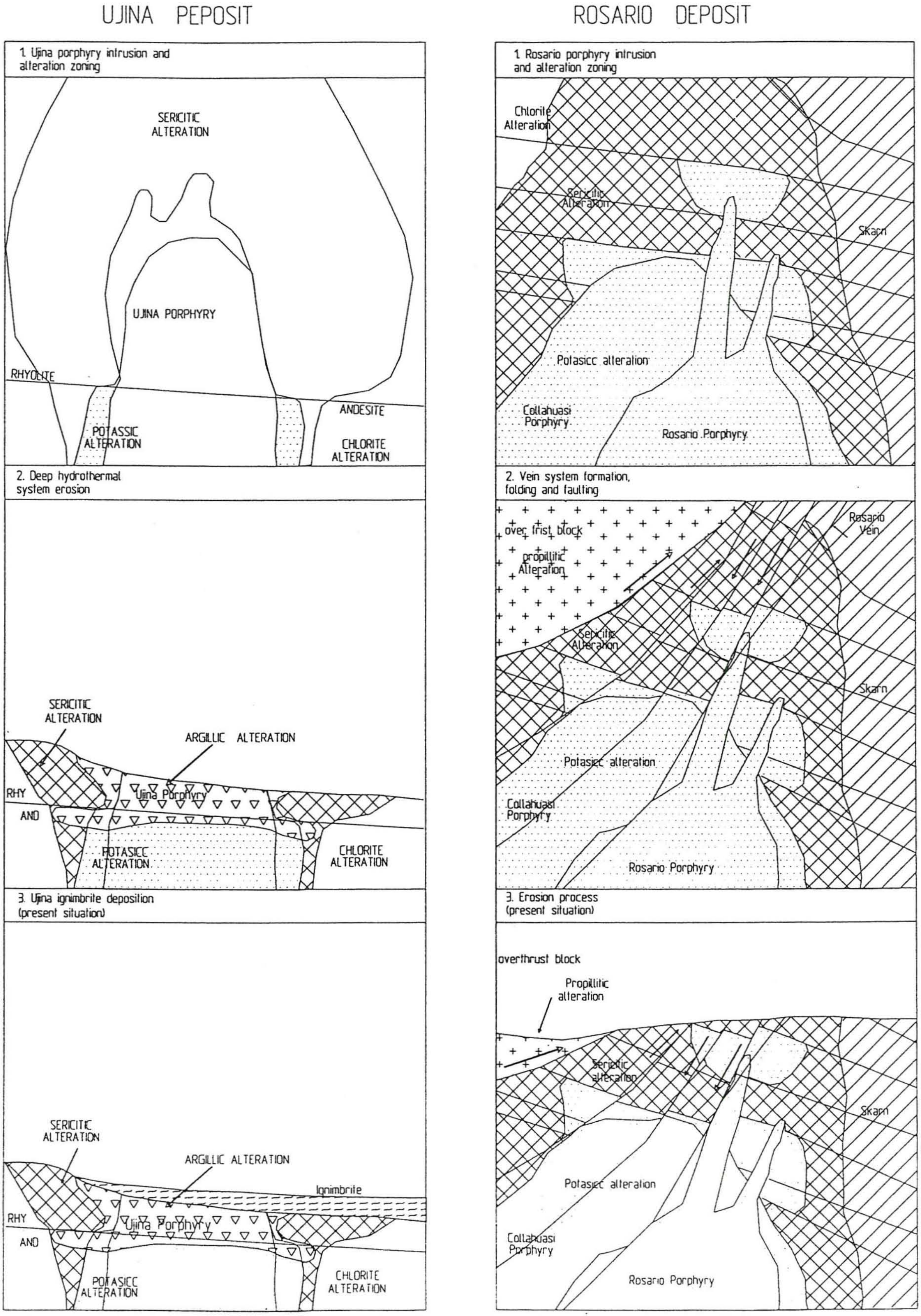


Fig. 7 - Collahuasi Porphyries Genetic Models

Models of Formation for the Ujina and Rosario Porphyry Deposits

The Ujina and Rosario deposits would have originated from the same parental magma, as indicated by their spatial proximity and similar ages of intrusion. However, the distinct tectonic settings and levels of erosion of each deposit produce the present differences (Figure 7).

In the case of Ujina, the intrusion of the Ujina porphyry is associated with an extensional tectonic regime as indicated by its location in a tectonically controlled basin. With this, the development of an intense enrichment process was possible, thereby allowing a blanket of high grade secondary enrichment to form. The erosive processes that reached a deep level of the hydrothermal system probably explain why high grade copper veins have not been found, as in Rosario. The alteration is predominantly potassic with sericitisation along the borders of the system and in the rhyolitic rocks.

At Rosario, the intrusion of the Rosario porphyry introduced the primary mineralization of the deposit, although in contrast to Ujina, there is an intense development of late, high grade vein mineralization at Rosario, which also produced an important increase in the grade of the primary copper. The compressive tectonic regime (uplifted horst) that affected the Rosario deposit produced the folding and tilting of the deposit itself. A later displacement towards the southwest placed a block of barren material over a large part of the deposit. The combination of intense erosion and strong structural control did not allow the development of secondary enrichment as at Ujina, but rather deposited sulphides along structures at great depths, presently at more than 600 m, and copper oxides in sectors of reducing rocks close to the surface and as cement in the exotic Huinquintipa deposit. The majority of the potassic and sericitic alteration zones and the sectors of hornfels and skarn are well preserved, which indicates that erosion only exposed the copper porphyry system to a moderate level.

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