Evaluation of potential primary or by-product Co and Mn resources in Chile

Brian Townley, Alejandro Díaz, Rodrigo Luca

Advanced Mining Technology Center (AMTC)
Facultad de Ciencias Físicas y Matemáticas
Universidad de Chile

English version: Translations by Rikki Sheldon and Susan Earnest
Revision: Brian Townley (AMTC), Mauricio González (CORFO)
August 2018

Table of contents

1. Introduction

The progressive worldwide development of new technologies and sources of energy, electric energy sources in particular, has resulted in a high demand for storage systems, primarily different types and scales of batteries, for common everyday technological equipment, as well as for the new generations of electric vehicles. Electric-mobility has already been introduced in the world and represents with certainty a progressive replacement of combustion vehicles, especially given the tendency and need to reduce contaminating emissions on a global level. This implies an increasing demand for batteries, where the use of lithium-based batteries is predominant in electric-mobility, typically the Li-Co, Li-Ni, Li-Co-Mn type, among others. Chile has the potential to become a worldwide lithium producer, being one of the countries with the biggest resources of this element, which opens a unique opportunity to diversify the local mining industry, ideally not only in the production of raw material, but also as a chance to give added value to mineral products, making it possible for Chile to manufacture batteries for the global market. Even though the production of lithium is viable, given the huge existing natural resources, the question still remains in reference as to the existence of mineral resources of cobalt and manganese and the actual possibilities of local production.

Based on the strategic requirements outlined for the national production and supply of cobalt and manganese metals, and as requested by CORFO (Comité Minería No Metálica), the assessment study herein of the potential mineral resources of cobalt and manganese in Chile was developed focused in the Atacama, Coquimbo and Metropolitan regions. In this study previous research reports have been integrated, including a bibliographical review of a wide range of information regarding past mining and historical districts involved in the production of cobalt and manganese in Chile (Townley et al., 2017), as well as studies carried out on site, with visits, sample collection and reviews carried out by the authors of the study herein (Townley et al., 2017b). In view of all of the gathered information and on-site studies, a discussion has been incorporated in reference to the potential exploration and production of cobalt and manganese in Chile, whether this be achieved from prime ore deposits for these minerals, or from potential deposits that have not yet been evaluated for the recovery as sub product, or also from mines where recovery from tailing deposits can be evaluated.

1.1 Objectives

The general objective of this report is to provide a global view of the potential resources of cobalt and manganese that exists in Chile, focused particularly in the Atacama, Coquimbo and Metropolitan regions, through the integration of the bibliographical review of existing data and information gathered during the visit to the sites of those districts that were most relevant within the regions involved in the study.

Specific objectives for this report are:

- Present historical records describing the past exploitation of cobalt and manganese in Chile.

- Describe mineral characteristics for the occurrence of these metals, the geological environment where they occur, and the feasibility for mineral recovery in mining and metallurgical operations for each type of occurrence.

- Describe the tectonic, magmatic, and metallogenic environments in which the largest potential for the occurrence of these metals exist, whether that be as deposits of primary ore or deposits where these metals could represent an important secondary product. Based on this and existing information, evaluate the resources that possibly exist and may be recoverable from tailing deposits at a low cost.

- Describe and evaluate some of the more important historical mining districts for the exploitation of these metals in Chile, including a data revision of resources and past production plus an estimation of the remaining potential geological resources, as well as information and sampling from field visits, these carried out to inspect and validate existing information.

- In consideration of the prevailing mineral occurrences in previously known deposits, evaluate the treatment and metallurgical recovery processes for these metals and analyze the technical and economic feasibility for their recovery as compared to other international products.

- Evaluation of the potential mineral resources that exists in Chile for cobalt and manganese, possibly from prime ore deposits for these metals or from the recovery of these as mining sub products from other main ores, and eventually, the possibility of recovery from tailing deposits.

1.2. Scope of the present study

The present study is based on the historical data and bibliographical reviews taken from existing public records, together with private or confidential information provided by CORFO. The information review and validation performed at the sites consisted of short visits to the districts that were most relevant or to those that presented opportunities of potential interest. The collection of samples at the sites for geochemical analysis was limited to a total of 50. The samples obtained were mainly from mine stripping or piles present at the different mining worksites visited, in some cases, from surface or underground outcropping.

It is important to mention that the focus of this study has been in the regions of interest, Atacama, Coquimbo and in a lesser degree, the Metropolitan region. However, and only based on bibliography, this review also includes other potential geological environments where Co and Mn could exist.

It is important to point out is that this report includes and concludes the previous activities and reports from the global study; therefore, a large part of the information is obtained directly from such previous activities and reports. (Townley et al.2017 a and b).

1.3. Methodology

For the development of the bibliographical study several different search engines were used, including: web journal browsers (eg. ISI Web of Knowledge, SCOPUS), Chilean university libraries, SERNAGEOMIN library and databases, the CORFO library, and public databases of ENAMI were explored in the development of this study. ANNEX 1 includes a list of all the publications and information found in digital format, compiled into a digital database available with this report. In addition to the digital searches, regional reports and databases from SERNAGEOMIN and other public services in the Atacama and Coquimbo regions were accessed and revised. The information obtained from SERNAGEOMIN is feasible to obtain directly from its webpage (www.sernageomin.cl) or from the SERNAGEOMIN library.

The on-site activities were carried out during three different campaigns, the first one in October of 2017 (Atacama and Coquimbo), the second one in December of the same year (Atacama) and the third one also in December of 2017, to the district Las Merceditas, in the sector of El Volcán, Cajón del Maipo (Metropolitan region). The visits were to the old and/or current mining worksites of the mining districts selected. In those cases, in which there were mining activities operating, contact was made with the operators in order to obtain local information that they could contribute with. No mapping tasks were carried out during the activities at the sites, only the revision and corroboration of the existing maps. The collection of samples was obtained mainly from the mining activities, stripping, stockpiles, and in some cases, outcrops. These samples were extracted only for corroboration purposes or to have an estimate of the concentrations of the elements of interest, and do not represent specific resources. A more detailed description of the activities on-site is presented in each study case.

1.4. Background and history

Historically, Chile has always been characterized as a mining country; formerly it was a global producer of nitrates (saltpeter) and presently it is a global producer and the primary owner of copper resources in the world. The single-product focus of the mining industry makes Chile an economically vulnerable country, presently dependent upon copper, its principal mineral resource. This dependence is intimately related to the geological characteristics of the Chilean Andean margin, a subduction-related continental arc, in which geological processes conducive to the formation of gigantic to behemothian-sized copper deposits have occurred. The most important deposits are the copper porphyry deposits. Other types of copper deposits exist, but to a lesser extent, such as skarns, strata-bound deposits, iron oxide copper gold (IOCG) deposits, and vein-type deposits; base metals occur in skarns and vein-type deposits; precious metals occur in vein-type deposits and breccia; and iron occurs in Iron oxide apatite (IOA) deposits and IOCG deposits.

Chile’s prime position as the principal producer of copper worldwide does not imply that there are no other metallic mineral resources in Chile. Chile has occupied important positions in the production of gold and silver and is currently an important producer of iron. It is worthwhile to also mention that the Chilean copper mining industry also has a significant production of by products such as gold, silver and molybdenum. This is a positive aspect of the Chilean mining industry, but also an aspect that overshadows and detracts exploration and exploitation of commodities different from copper, or the recovery of by-products different from gold, silver or molybdenum recovered from the same copper deposits. These negative aspects of the Chilean mining industry have long been known, detected as a weakness since the 1960s (D’Aubarede, 1969). Historically, there have been efforts by the state to raise interest and increase investment in the exploitation of other mineral resources; however, there has been no significant development in this direction as compared to copper mining.

Currently, technological advancement in the development of electric vehicles has forced the use of a diversity of mineral products that have, in the past, observed a lesser demand in the market. The widespread growth of lithium-nickel, lithium-cobalt and lithium-cobalt-manganese battery technologies has generated an increasing demand for these metals, opening a real window of opportunity for the diversification of the mineral production in Chile. From the perspective of mineral resources, Chile has, in addition to copper, enormous resources of lithium and is a strong global competitor as compared to other producers such as Bolivia, Argentina and Australia. On the other hand, internal production of lithium could be used for the generation and manufacture of value-added products including, among others, lithium-ion batteries. Value-added strategies of this type require searching for, evaluating, and exploiting other metallic resources. Among those mentioned for battery fabrication, cobalt and manganese both exist in Chile.

In the past, deposits of cobalt and manganese have been exploited in Chile. Cobalt was exploited last century until 1944 and manganese was exploited until more recent times in 2009 (Sernageomin, 2017). The cobalt deposits exploited were found in the Atacama, Coquimbo and Metropolitan regions. The documented exploitation for cobalt started in 1844, in the middle of the XIX century, in the Tambillos district of the Coquimbo region and in the El Volcán and Río Maipo sectors of the Metropolitan region. In 1865 and 1875, cobalt deposits were mined in the San Juan district, in the vicinities of Huasco and also in areas near Copiapó. The production of cobalt since then was maintained, with various interruptions, until 1944. Cobalt was primarily exploited for exports; fundamentally for its use in steel alloys; and the highest demand was during World War II. The end of the war marked the closure of mining camps established for exploitation and production. The districts with the most production in the aforementioned period of exploitation were the districts of San Juan, in the Atacama region, and Tambillos, in the Coquimbo region.

Historically, the exploited manganese deposits were found in the Atacama and Coquimbo regions; their exploitation was primarily used for national demand (Sernageomin, 2017). Documented exploitation of manganese started in the beginnings of the XX century in the Corral Quemado district of the Coquimbo region, followed by other nearby districts such as Lambert, El Romero, La Liga, Arrayán and Fragua, in the same region, and some minor deposits in the Atacama region. Manganese production in Chile has been directed principally for use in steel alloys; a production which has been maintained in part by the company Manganesos de Atacama S.A. until 2009 (Manganesos de Atacama S.A., 2009). Following this, only small-scale productions remained; and currently, the principal mines are in the process of official closure.

1.5. Metallogenesis of Chile and environments with cobalt and manganese potential

1.5.1. Historical deposits with Cobalt as the principal ore

The following information has been synthesized from Sernageomin reports as summarized in a proposal prepared by Sernageomin for CORFO (Sernageomin, 2017). The deposits with cobalt as the principal ore exploited in Chile and distributed in the Atacama, Coquimbo and Metropolitan regions correspond primarily to vein-type, breccia and, occasionally, manto-type ore deposits hosted within metamorphic rock sequences, intrusive volcanics and, in some cases, sedimentary rocks. With respect to the historical production of cobalt, it has only been exploited in significant quantities from primary ore deposits in two districts: the San Juan district of the Atacama region and the Tambillos district of the Coquimbo region. The primary mineralization of cobalt is found in the San Juan district as Cobaltite, a cobalt sulfoarsenide deposited in vein systems with average ore grades valuing up to 1.6% Co. It is worthwhile mentioning that the majority of historical production in this district was directed toward the exploitation of oxidized secondary ores, primarily the cobalt arsenate Erythrite, found in mineralized ore bodies with ore grades of up to 6.4% Co. The Tambillo district has groupings of bedded deposits with primary copper and cobalt ores. Here Cobaltite is the primary cobalt-bearing mineral, and mean ore grades of 4 – 5% Co were reported in 1968. In the Metropolitan region, former exploitation of vein-type ore deposits in the El Volcán and the Río Maipo (Merceditas) sectors were reported as primary sulfide ore deposits with average ore grades ranging from 0.5 – 0.7% cobalt. Maximum values for the ore grades were measured to be 2.4 – 2.58% Co. Another district in which copper and cobalt exploitation has been described is Carrizal Alto in the Atacama region, where deposits present copper and cobalt mineralization with cobaltite as the primary mineral. No assay data is reported for this last sector.

1.5.2. Historical deposits of Manganese as the principal ore

The following information has been extracted from Sernageomin reports and summarized in a proposal prepared by Sernageomin for CORFO (Sernageomin, 2017). The principal manganese mines exploited industrially are associated with manto-type deposits and, on a smaller scale, in vein-type deposits. These are found in the Coquimbo region hosted within two principal rock units called: the Arqueros Formation and the Quebrada Marquesa Formation. They are also found in the equivalent formation units in the Atacama region. The largest and most significant deposits are found in the Quebrada Marquesa Formation, which are comprised primarily of marine sediments. The most important district both for its production and ore quality is the Corral Quemado district. The next most significant deposits are in the region of Coquimbo, in the Arrayán and Fragua districts, followed by deposits of lesser significance in the Las Cañas, Talcuna and Arqueros districts. Of even lesser significance are the mineralized bodies in the Sierra La Bandera district, north of Freirina in the Atacama region. The ore-bearing minerals in these deposits include pyrolusite, braunite and psilomelane as well as copper and silver-bearing minerals. The highest ore grades reported oscillate between 42 and 52% Mn. In more recent productions, before closing, ore grades reported to Sernageomin fluctuated between 16 and 30% Mn. These were reported from deposits in the Coquimbo region by small-scale mining operations, the most relevant being Manganesos Atacama S.A.

1.5.3. Metallogenesis of Chile and environments with cobalt and manganese potential

The tectonic-magmatic evolution along the Chilean Andean Margin has been characterized from its early origins for its distinct copper metallogenic imprint, this since the beginnings of the oldest magmatic arcs in the Paleozoic-Triassic. In this geologic time period, various copper porphyry deposits were formed in a north to south distribution all along the axis of the Paleozoic-Triassic volcanic arc. This metallogenic belt extends southward from the Tarapaca region along the principal axis of the Andes mountain range before crossing to Argentina, south of the Atacama region. The deposits in this belt are not economically significant; they include: Characolla, El Loa, Lilian, Tornasol, Lila and Río Frío in Chile, Alcaparrosa and San Jorge in Argentina, with ages ranging from 285 – 195 Ma (Fig. 1.1) (Maksaev et al., 2007; Maksaev, 2001). None of those in Chile are currently being developed economically because of their low ore grades and small volumes.

Since the Upper Jurassic, the evolution of the Chilean Andean Margin has been characterized by the occurrence of copper deposits of various types and sizes. The principal metallogenic belts in Chile are described here with a brief summary, starting from oldest to youngest.

The characteristic principal mineralization from the Jurassic time period is copper, generally deposited in an extensional type environment associated with a volcanic arc. The deposits from this period are strata-bound copper distributed along the coastal mountain range from the Tarapacá to the Atacama region, from north of the city of Tocopilla to south of Chañaral (Fig. 1.1). The primary mineralized zones in these deposits present chalcopyrite, bornite and chalcocite with the presence of silver as a by-product of copper recovery. Despite that these deposits are characterized by a high iron imprint, iron mineralization comprises mainly oxidized mineral phases such as hematite, pyrite being an uncommon mineral. From a metallogenic perspective these deposits do not present significant concentrations of cobalt nor manganese.

In the Lower Cretaceous, the development of copper porphyries in the Antofagasta, the Atacama and the Coquimbo regions defines a marked diversification in metallogenesis. These deposits are small in comparison with the younger deposits of the same type (e.g. Eocene – Oligocene in northern Chile). In the Atacama and Coquimbo regions, the volcanic arc during this time period extended from north of Caldera to south of Coquimbo and was characterized by iron oxide apatite (IOA) and iron oxide copper gold (IOCG) deposits located primarily in or related to the Atacama Fault System (AFS). The IOA-type iron deposits represent the main ore source for the national iron mining industry. The principal ore in these deposits is magnetite; to a lesser proportion, there are hematite and trace amounts of sulfide mineral phases like pyrite, arsenopyrite, chalcopyrite and other minerals. Given the affinity between cobalt and iron, these deposits could present potential for the occurrence of cobalt as a residual by-product during the recovery of iron, an aspect that will be described later on in this study. Associated with this same belt of iron deposits, both in the AFS and in the eastern margin of the arc, are IOCG-type deposits. These deposits are exploited for their copper ore (chalcopyrite) and have gold as a principal by-product. Despite high-concentrations of iron in these deposits, principally magnetite, as these are not considered ore in production, they end up as a residual product in tailings. The reprocessing of these tailings by CMP allows economic recovery of magnetic iron, and it is worth mentioning that the potential to extract other elements/minerals of value from these residues exists. The IOCG-type deposits in other parts of the world and in Chile are characterized by a distinct geochemical signature defined by Fe-Cu-Au along with other elements such as rare earth elements (REE), cobalt, uranium and thorium. Although they have a geochemical signature for many elements of potential economic interest, mineral occurrence and their concentrations for Chilean IOCGs (e.g. Manto verde, Candelaria, Distrito Punta del Cobre) have not yet been studied for the purpose of evaluating the metallurgical mineral recovery potential. Farther south, in the Lower Cretaceous belt that extends from south of Coquimbo to the Valparaiso and Metropolitan region, the metallogenic characteristics change, showing a predominance of strata-bound copper deposits, the largest of this type being El Soldado in the region of Valparaiso. These deposits are the same type as those appearing to the north in the Upper Jurassic belt and have a prime copper geochemical signature with silver as a by-product. In the southern part of this metallogenic belt, in the same zone as the strata-bound deposits, the presence of copper-bearing skarn deposits is found, the most important of which are in the Cabildo district in the Valparaiso region and in the San Antonio and Panulcillo districts of the Coquimbo region. In addition to the diverse types of deposits associated with the magmatic arc evolution during the Lower Cretaceous, it's worth mentioning the occurrence of vein-type copper and gold deposits, the largest of which are found in relationship with the AFS. Finally, in spatial and likely also in genetic relationship to the Chilean iron belt, copper-cobalt vein and breccia deposits are found; the most relevant districts are San Juan, in the Huasco province of the Atacama region, and Tambillos, in the Coquimbo region. Also associated with this volcanic arc, in the intra- and back-arc regions, manganese deposits are present; the most significant ones being found in the districts of Corral Quemado, Fragua, La Liga, Lambert, etc. in the Coquimbo region.

Associated with tectonic regime changes along the South American margin during the upper Cretaceous, brought on by the separation of the South American and African continents and the expansion of the Atlantic oceanic floor, extensional conditions shifted to compressional. As a result, metallogenic development yielded a considerably smaller mineralization footprint, leaving behind only copper-gold vein-type deposits, silver vein-type deposits and, to a lesser extent, copper porphyry deposits (Fig. 1.2) of small sizes, low concentrations and low economic potential. In the past, the most important silver deposits in the nation have been distributed in the Caracoles, Chimberos-Tres Puntas, Chañarcillo and Arqueros districts of the Antofagasta and Coquimbo regions. Further south, between the Coquimbo and the O´Higgins regions, vein-type deposits of gold and base metals of meso- to epithermal origin are present; the most important ones are in the Alhue district of the O´Higgins region and the Bronces de Petorca district of the Valparaíso region.

Following tectonic compression during the Upper Cretaceous and the closure of the Lower Cretaceous back-arc basins, continuous changes in convergent conditions between the continental and the oceanic plates in the tectonic environment along the South American margin created a transpressive environment during the period between the Paleocene and the Lower Eocene. During this period, along the Andean margin extending from southeast Peru into northern Chile, the magmatic arc of this new tectonic environment was emplaced to the east of the Upper and Lower Cretaceous volcanic arcs. During this period, a distinct metallogenic imprint of copper with lesser quantities of silver and gold was formed, with development of copper-molybdenum porphyry deposits, vein-type deposits containing gold and silver and hydrothermal breccia deposits containing copper mineralization (Fig. 1.2). World-class copper-molybdenum porphyry districts are found in this belt between the Tarapacá and Atacama regions, including Mocha, Cerro Colorado, Spence, Lomas Bayas and Relincho, among others. In this belt, gold and silver epithermal vein-type deposits are also present, such as those existing in the Faride, San Cristobal, El Peñon and Guanaco districts in the Antofagasta region.

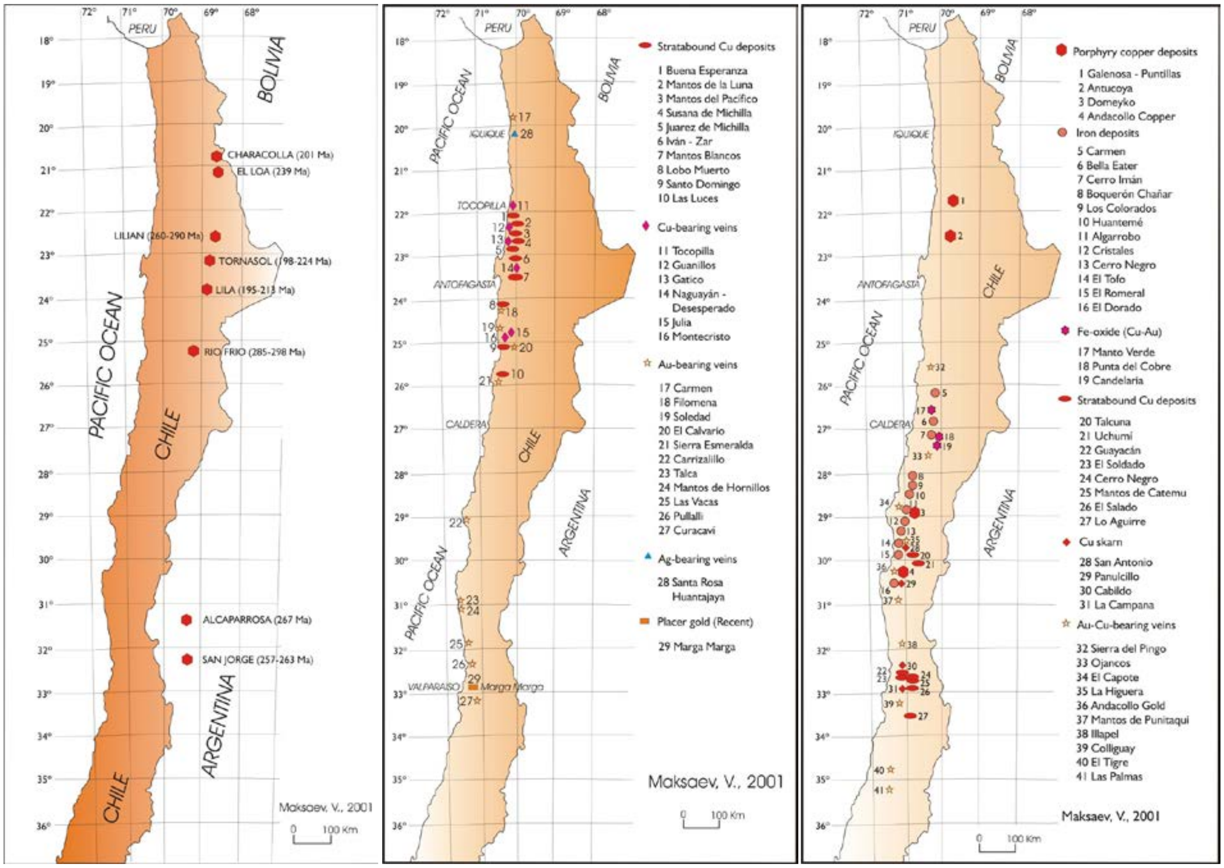


Figure 1.1. Copper porphyry deposits from the Paleozoic-Triassic (left); strata-bound deposits of copper and vein-type deposits of gold and silver from the Jurassic (center); copper-porphyry deposits, iron oxide apatite (IOA) deposits, iron oxide copper gold (IOCG) deposits, strata-bound copper deposits, copper skarns and vein-type deposits of copper-gold from the Lower Cretaceous (right) (Maksaev, 2001).

After the Paleocene – Eocene tectonic, magmatic and metallogenic developments, the most important metallogenic province in the north of Chile was emplaced to the east of this previously-mentioned belt during the Upper Eocene – Lower Oligocene. This belt contains the mega copper-molybdenum porphyry deposits that extend from the Tarapacá to the Atacama region. This belt is associated both spatially and genetically with the Domeyko Fault System (DFS), a deformation zone that extends in a NS direction for over 1300 km. In this belt, the most important copper-molybdenum porphyry deposits in the country are found, among them Quebrada Blanca – Collahuasi, Chuquicamata, Escondida, El Salvador, and, farther to the south, El Morro – La Fortuna (Fig. 1.3) districts. It is worth mentioning that significant gold signatures exist in all of these deposits, most of them have an average concentration of 0.25g/t. This means that the recovery and production of gold as a by-product of copper production may represent the most important gold production country wise. Other important by-products, recovered with molybdenum, include rhenium. Other possible elements/minerals of potential economic interest derivable as a by-product are unknown or have not yet been evaluated. However, considering the gigantic volumes of exploited and processed rock, the tailings piles that have been generated could be an interesting target for exploration and evaluation of opportunities, and the possible presence of cobalt and/or manganese should not be ruled out.

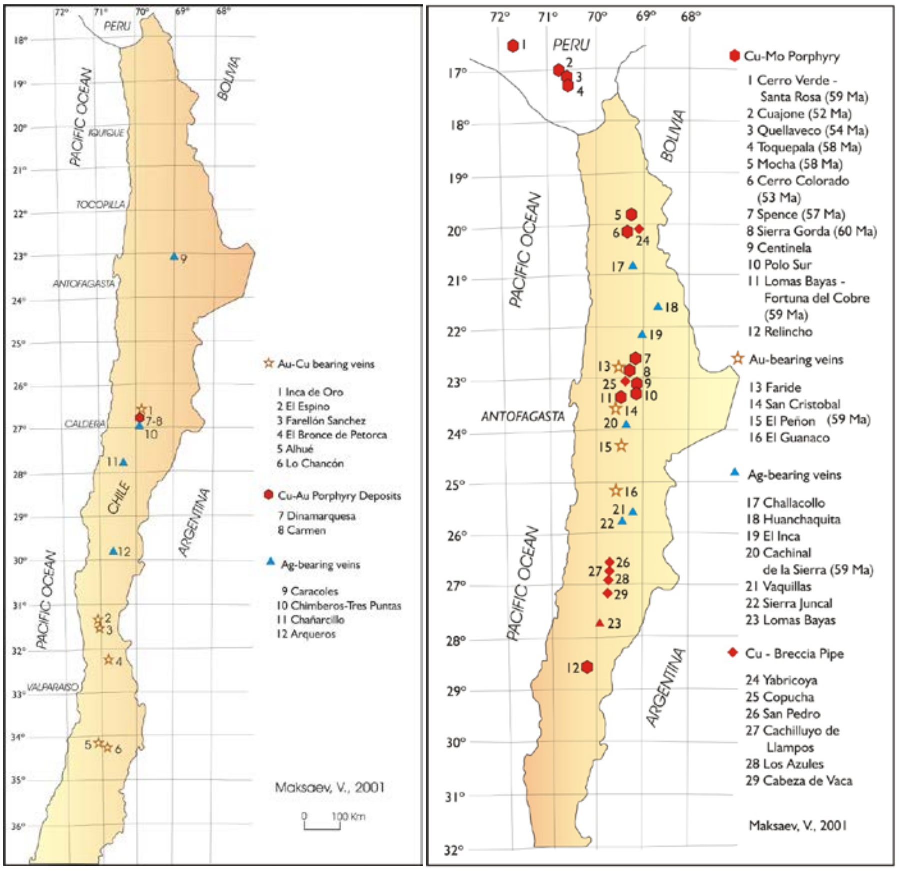


Figure 1.2. Metallogenic belts of the Upper Cretaceous (left) and Paleocene – Lower Eocene (right). Maksaev (2001), Maksaev et al. (2007).

Finally, between the Miocene and the Pliocene, tectonic and magmatic evolution on the Andean Margin moved to central Chile and to the east, towards the region bordering with Argentina (Fig. 1.3). During the evolution of the magmatic arc in the Miocene, gold-bearing vein-type and breccia deposits of epithermal origin occurred in association with gold porphyry deposits in the Maricunga belt of the Atacama region. Farther south, gold-bearing deposits of epithermal origin occurred, the most important being Pascua-Lama in the Atacama region and the El Indio district in the Coquimbo region. Farther south, in the high Andes and stretching from Salamanca towards the Maule, mega-deposits of porphyry copper-molybdenum type occurred; these include: Los Pelambres – Pachón, Río Blanco – Los Bronces, and El Teniente, where these last two may be the largest of its type in the world. To the south of El Teniente, various copper-molybdenum porphyry prospects are found; the most important one that has the greatest potential is Rosario de Rengo in the O´Higgins region. In comparison with the equivalent deposits in the mega-porphyry belt in northern Chile, only molybdenum represents a relevant by-product, gold concentrations most commonly too low to be of importance. The possibility that other important by-products may exist has not yet been studied in detail or is not described in the literature. Nevertheless, the possibility of elemental/mineral occurrences of potential economic interest, like unevaluated Co and Mn contents, should not be ruled out.

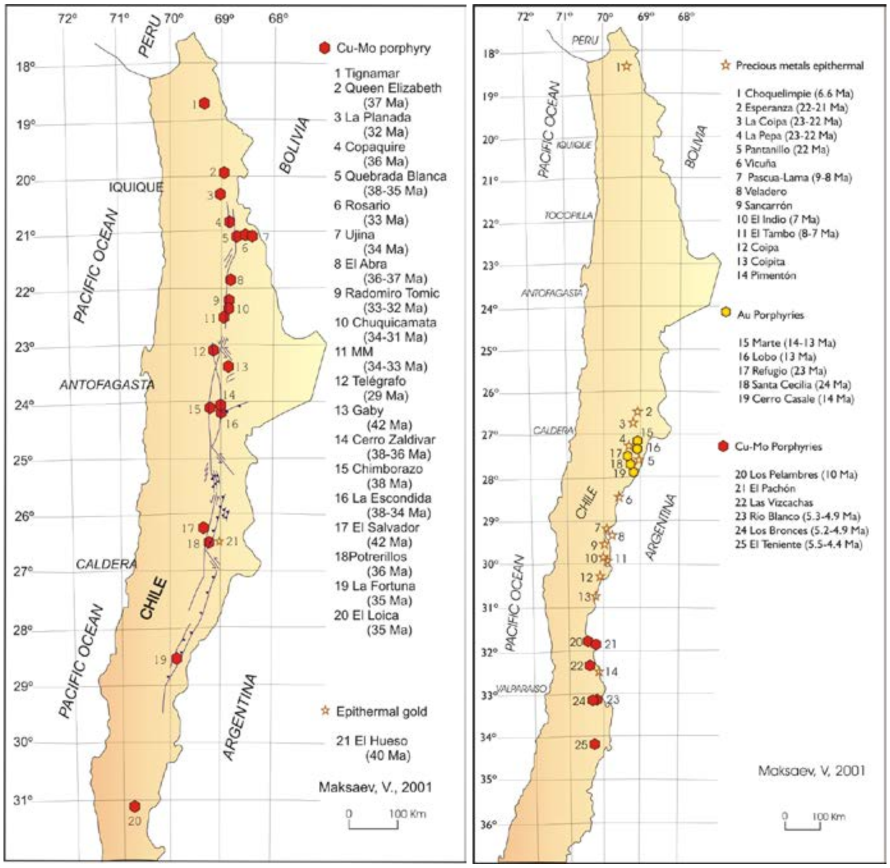


Figure 1.3. Metallogenic belts of the Upper Eocene – Lower Oligocene in the north of Chile (left) and of the Miocene in central Chile (right). Maksaev (2001), Maksaev et al. (2007).

It is worth mentioning that to the east of the mega-copper-molybdenum porphyry belt in central Chile, vein-type deposits with cobalt and copper mineralization have been exploited in the El Volcán and Alto Río Maipo sectors of the Metropolitan region. Farther south, in the Alto Maule valley, vein and manto-type iron deposits with lesser copper mineralization and positive anomalous concentrations of cobalt have been described, yet no concrete data exists. In both cases, the age of these deposits are unknown but the host rock corresponds to stratified volcanic and sedimentary rocks of Cenozoic age.

Despite that the principal and most important mineral deposits in the country occur between central and northern Chile, it is worth mentioning that a diversity of metallic ore deposits exists in southern Chile. In the Los Lagos region polymetallic deposits have been described; a metallogenic signature which is even more relevant in the Aysén region. In this last region, zinc-lead skarn deposits (Zn, Pb, Cu, Au and Ag) and precious metal vein-type deposits of epithermal origin (Au-Ag) have been exploited. The first are found in the El Toqui and Puerto Cristal districts and the second in the Cerro Bayo district. In the Aysén region, vein-type polymetallic deposits are common and have high concentrations of Au-Ag-Zn-Pb-Cu. They have not yet been evaluated for other elements. Unevaluated tailings of importance exist for all of these deposits. Farther south, in the Magallanes region, the tectonic and magmatic environments are very different from the rest of Chile. In this region, towards the Argentinian border, there exists a rock sequence called the Rocas Verdes belt, interpreted as an aborted expansion rift. In this belt, polymetallic mineral deposits exist, interpreted as oceanic floor related volcanic massive sulfide (VMS) deposits, or perhaps orogenic deposits formed along suture and shear zones during closure. Among those deposits that have been exploited and are currently in evaluation, Cutter Cove can be mentioned. Even if there are no published records for this deposit, its mineralization is considered to be of a polymetallic character and the existence of Co and/or Mn has not yet been evaluated.

Finally, also worth mentioning is the existence of laterite type deposits of Ni-Co, as a result of weathering on ultra mafic rocks (streamers) in the province of Valdivia, region of Los Ríos (Zamarsky et al., 1973). At the study sites (Botija and Three Chiflones) the samples and description of laterite profiles of up to 7 meters height determined maximum concentrations of 0,13% CoO and 0,92% NiO (Zamarsky et al., 1973).

2. Types of deposits in Chile with cobalt ore potential

Considering the metallogenic evolution of Chile, a brief description of those metallogenic environments in which potential cobalt mineralization may exist, be it as primary ore in cobalt deposits or as potential by-product of a primary exploitation of iron and/or copper deposit in which cobalt may represent a production credit, is provided. Finally, possible sources of cobalt as mineral / geochemical occurrences in tailings are reviewed.

2.1. Deposits with the potential for cobalt as a primary ore

According to literature and the historical records in Chile, despite that primary cobalt ore deposits have been exploited in the past, these correspond to districts of limited scale in which cobalt was mined together with copper. Among these are the deposits from the San Juan and Carizzal Alto districts, near the city of Huasco in the Atacama region. In these districts, the mineralization presents itself in quartz vein systems where cobalt mineralization occurs primarily in the form of sulfoarsenides (cobaltite) with an upper oxidized horizon containing erythrite (cobalt arsenate). The vein bodies are found hosted in metamorphic rocks from the Paleozoic - Triassic period and in intrusive rocks associated with the coastal batholith. Cobalt exploitation activities in this district have been closed for a long time. The ruins of the most important historical mining camp, La Cobaltera, are now only a tourist attraction. It is worth mentioning that in the surrounding area, mining activity from small-scale mines still exists. They exploit oxidized copper minerals and send them to the ENAMI mineral processing plants in Vallenar.

Farther south, in the Coquimbo region, another important historical source of cobalt were the copper and cobalt deposits of the Tambillos – Minillas district. In this district vein, minor breccias and manto type deposits exist, these with copper sulfide and sulfoarsenide (cobaltite) mineralization. In the upper oxidized levels secondary mineralization of copper predominates with only rare occurrences of erythrite. Currently, there exists exploitation in Tambillos; however, this exploitation is concentrated on copper as a primary ore, and there is no information about cobalt recovery. Given that the present-day and past exploitations are oriented towards the recovery of copper, it is of potential interest to evaluate the occurrence of cobalt in the tailings of this district.

Another mineral occurrence where cobalt is the primary ore is found in the historical records of mineral exploitation corresponding to vein-type deposits located in the El Volcán and Alto Río Maipo sectors of the Merceditas district. These are small and narrow vein systems, individual veins with an average thickness no larger than 30 cm.

The documented districts in the Atacama and Coquimbo regions are spatially and temporally associated with the iron belt of Chile and related to magmatic arc evolution during the Lower Cretaceous. They have an affinity with iron oxide copper gold and, to a lesser degree, with iron oxide apatite deposits. For the vein systems in the Alto Maipo zone of the Metropolitan region, the age of the mineralization is unknown. For this reason, there is no information to help define the metallogenic relationships of these deposits within the tectonic and magmatic evolution of central Chile. These deposits have no affinity with the copper porphyry belt located to the west of these districts.

Today, the described deposits could present some remnant potential for cobalt as a primary ore; however, this requires evaluation of potential resources in depth. In accordance with existing records from the San Juan district, past exploitation reached a maximum depth of approximately 100m, which implies that exploration drilling to deeper depths may discover non-exploited resources. In Tambillos the situation is similar, and despite that current copper exploitation has been extensive and deep, no publically available information with respect to the potential for cobalt exists. In both districts, and possibly also in the Carrizal Alto district, there still exists remnant exploratory potential with regard to the search for primary cobalt ore deposits.

2.2. Deposits with potential for cobalt as a by-product

Based on the metallogenic evolution along the Chilean Andean Margin and the affinity of cobalt with iron and arsenic in low sulfidation hydrothermal environments, the principal metallic mineral deposits that can be associated with the occurrence of cobalt as an important by-product or credit are, primarily, the iron oxide copper gold (IOCG) deposits that occur in the Lower Cretaceous metallogenic belt (Mathur et al., 2002; Maksaev et al., 2007; Barra et al., 2017; Fig. 2.1). In this belt, the La Candelaria deposit and the deposits in the Punta del Cobre district could represent targets for evaluation. Although cobalt recovery has not been reported as a an operational by-product or credit, given the type of deposit and the associated mineralization, there may exist a non-evaluated potential. Another deposit of this type for which no cobalt recovery has been reported but where its occurrence cannot be discarded, includes the Manto Verde deposit, located to the east of Chañaral and found along the Atacama Fault System (AFS).

Other deposits in which cobalt may be present as a potential by-product or credit could be the iron oxide apatite (IOA) deposits that are also the principal source of iron in Chile. These deposits are distributed along the AFS between the Atacama and Coquimbo regions (Fig. 2.1); the principal deposits being exploited are: Los Colorados, El Algorrobo, and El Romeral.

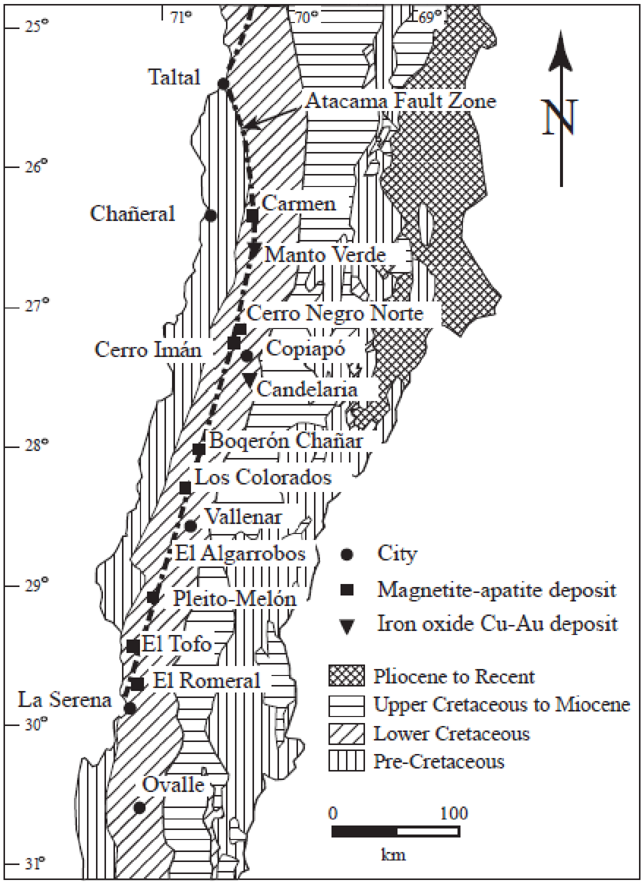


Figure 2.1. Spatial distribution of the IOA-type (magnetite - apatite) and IOCG-type (iron oxide copper gold) deposits in the iron belt of Chile, Lower Cretaceous magmatic arc. Taken from Mathur et al. (2002).

Finally, despite that the highest probability of cobalt ore existence is associated with IOCG or IOA-type deposits, the possible presence of cobalt minerals associated with copper porphyries should not be ruled out. Given that the affinity of cobalt in sulfides occurs with arsenic and that this element represents a penalty in copper concentrates, it would be advisable to evaluate these types of deposits for existence of cobalt. In addition, existence of cobalt in pyrite in porphyry copper deposits has been documented, as described in studies published on these types of deposits in northern Chile (Carballo, 1979; Pincheira et al., 1997). Despite that cobalt concentrations in arsenic minerals and/or pyrite could be low; depending upon mineral occurrence and association with copper or molybdenum mineralization, cobalt could be recoverable in the same metallurgical process and represent a relevant credit, which at present is lost to the tailings. Other types of deposits in which the presence of cobalt could exist are polymetallic base metal deposits; these include, for example, vein-type deposits and skarns in the Aysén region or massive sulfide deposits in the Magallanes region. There are no records to the respect; however, since these are unconventional deposits in Chile, little is known about them.

2.3. Tailings deposits with potential for cobalt

In Chile, a large numbers of tailing deposits exist, these generated by over 100 years of mining activities of the small, medium and large mining industries. Presently, the large mining industry annually generates enormous volumes of environmental passives that are hardly ever evaluated for their potential as mining assets. In the case of cobalt, the minerals that potentially could contain it are not recovered within the mining process for copper, gold or iron, and would instead be disposed together with the gangue in the tailings. For cobalt sulfides, sulfo-arsenides and arsenides, similarly as with pyrite and arsenopyrite, these minerals would become concentrated in the tailings. Given that the occurrence of cobalt is unknown in the majority of Chilean deposits (be they copper, gold, iron or combinations of the above), it is difficult to determine at present if this element could constitute an element of potential interest, and if present, even more difficult to determine whether it would be metallurgically recoverable or not.

At this moment, there are studies underway striving to determine the potential elements/minerals of economic and strategic interest that could be contained within the tailings. In the state-of-the-art study about tailings in Chile (Caraballo et al., 2017), where valuable information regarding the 2016 Tailings Registry published by Sernageomin has been referenced (http://sitiohistorico.sernageomin.cl/mineria-relaves.php), geochemical results giving concentrations for multiple elements found in Chilean tailings have been described. The data from this study allows for a first rough idea of what could represent the potential for cobalt. According to this study, the maximum reported concentrations are found in samples from the tailing deposits of Delirio 3, from Punitaqui in the Coquimbo region (190 ppm cobalt), María Isabel (98 ppm Co), in the community of Tierra Amarilla, and in Filtrados de Potrerillos in the Diego de Almagro community (88 ppm Co), the last two in the Atacama region.

According to the original deposit type, there exists a wide variety of minerals in which Co could be present. The most common mineral groups are the sulfides, sulfoarsenides, arsenides, and oxides. Co may substitute transition metals like Fe and Ni in some minerals. Co is almost always found as a by- or co-product of other base metals in the mining industry, primarily Cu and Ni. For this reason, it is expected that in Chile it will be associated with the principal national deposits, from which Cu is extracted, and especially those deposits with high sulfide contents. The typical ore grade for Co associated with magmatic – hydrothermal sulfide deposits is 0.1% (British Geological Survey, 2009). The maximum value for Co concentrations, measured in Chilean tailings piles, is 0.019%, which is too low to be of economic interest alone. Nevertheless, if taken into consideration the fact that some tailings in Chile are being exploited and processed for other elements, primarily copper, then the opportunity opens itself to evaluate them for the recovery of cobalt as a by-product. It's is also worthwhile mentioning that, in the Sernageomin study of tailings in Chile (Catastro de Relaves), only one sample was obtained for the majority of the tailings deposits; and that these samples were taken near the surface, at sampling depths no greater than 2m.

These facts indicate that the low concentrations of cobalt reported in Chilean tailings is not a conclusive measurement, especially considering that sulfides and sulfoarsenides associated with cobalt have a high specific gravity and, therefore, a tendency for gravitational segregation during transport, causing them to settle to greater depths. On the other hand, as is the case for older tailings, sulfide and sulfoarsenides in oxidizing environments have been subjected to oxidation, hydrolysis, and possible leaching, leading to potential Co re-concentration processes, similar to the enrichment processes observed for copper.

3. Types of deposits in Chile with potential for manganese ore

In consideration of the metallogenic evolution of Chile, those metallogenic environments in which mineral resources with manganese have been documented and exploited, are briefly described. Additionally, a review of possible manganese sources as mineral/ geochemical occurrences is presented, whether these as possible by-products or perhaps contained in tailings deposits.

3.1. Primary ore deposits of manganese

The manganese deposits where industrial exploitation has been developed are found distributed principally in the Coquimbo region and, to a lesser extent, in the Atacama region (Sernageomin, 2017). The most important economic deposits correspond to bedded deposits of sedimentary – volcanic origin and also occur in epithermal vein bodies. Stratigraphically, these deposits are found hosted in two principal lithological units called the Arqueros Formation and the Quebrada Marquesa Formation in the Coquimbo region and in the equivalent lithological units in the Atacama region (Sernageomin, 2017).

The most important deposits are hosted in rocks of the Quebrada Marquesa Formation, and the most important mining districts in this formation are those that present the greatest prospects for the exploration of remnant or undiscovered resources. Historically, the most important district has been Corral Quemado, as much for production as for quality. The next most important districts were Arrayán and Fragua, followed, in decreasing importance, by the Las Cañas, Talcuna and Arqueros districts, located in the Coquimbo region and the Sierra La Bandera district found to the north of Freirina in the Atacama region (Sernageomin, 2017). These districts are described later on in this report.

With respect to the geological environments in which these types of deposits were formed, mainly sedimentary-volcanic rock units typical of fore- intra- and back arc environments, these had their most significant development in northern and southern Chile during the Upper Jurassic and Lower Cretaceous. The target for mineral exploration should hence be oriented towards geological environments in which stratigraphic sequences of Mesozoic sedimentary and volcanic rocks are present. Given that manganese minerals never have been of high economic importance in Chile and that, on the other hand, national production needs and exports could be satisfied with production in the known districts in the Coquimbo and, to a lesser extent, in the Atacama regions, exploration activities for this resource have been scarce. Nevertheless, given the widespread occurrence of geological environments congruous to the formation and genesis of these deposits, potential for these deposits remain.

3.2. Other possible sources of manganese

An interesting project for the exploration and potential production of manganese outside of the Coquimbo and Atacama regions is the Los Pumas mining project located in the community of Putre, at 175 km to the NE of Arica and 35 km NNW from Putre, itself in the Arica and Parinacota region. The project "Manganeso Los Pumas", whose owner is Minera Hemisferio Sur S.C.M. (MHS), includes a proposal for the exploration, mineral extraction and processing of manganese (Mn) from its deposit with the goal of producing Mn concentrate to sell in the international market. It has been estimated that the Los Pumas deposit holds 18.3 million tons of indicated reserves, at a cutoff grade of 7.8% Mn, and more than 5.4 million tons of inferred resources. The suggestion is to exploit the mineral in an open pit, to run 3 operations simultaneously, and to process it in a processing plant using crushing, grinding and dense medium separation methods. In this way, it is proposed that production will be on the order of a nominal 400 thousand tons per year of concentrate, which will be transported in trucks carrying 30 tons each to a collection yard in the industrial zone of Arica. This mining project is currently on hold due to the revocation of environmental permits and strong resistance by the local communities.

In the same region, 175 km from the city of Arica, the webpage of the company CAMIN Mining Engineering and Exploitation (http://www.camin.cl/proyectos-mineros/proyecto-manganeso/) describes the mining project, *Proyecto Minero Mar y Cielo*. The information presented for this project is cited below, as presented in the original web page. It should be noted that neither the exact location of the deposits nor details describing geological characteristics are mentioned.

Mar y Cielo Mining Project, (CAMIN)

"Executive Summary: The objective of the *Mar y Cielo Mining Project* is the open pit exploitation of manganese mineral, its crushing, milling and concentration in a processing plant, and the exportation of manganese concentrate through the port of Arica. The project will be executed in two stages. In the first stage, production will be started over a period of 6 months following the reception of an investment capital valuing 10 million dollars. The second stage, requiring an investment of approximately one hundred eighty million dollars, consists of the construction of a concentrator plant, a solar energy plant, and a train station. The solar energy plant alone costs US$ 110 million. The studies performed by *Minera Mar y Cielo* have defined the existence of manganese mineral resources exceeding 600 million tons (Mt) with an average ore grade of 47% Mn. A mining plan has been drafted for the *Mar y Cielo Mining Project* showing rates of extraction on the order of 22,000 tons of mineral monthly; and annual export of approximately 1.3 million tons (Mt/year) of Mn concentrate. Taking into consideration that current explorations covers less than 30% of the mining concession, these figures give the mine an operating life of approximately 22.8 years."

"Mining Complex: The mining complex is located in the Arica and Parinacota region, 175 km from Arica. Exploration campaigns have helped establish that manganese mineralization is found over a distance of 3.0 kilometers and in deposits up to 700m wide. The mineralized body is close to the surface and can be characterized as an in-situ high-grade tabular body, favoring conventional open-pit methods of exploitation for a pit measuring from 20 to 30m deep. At the moment, exploration campaigns have found potential resources on the order of 60.4 million tons with approximately an estimated 40 to 51% Mn content; this is over only 360 Ha of the 1,200 Ha that must be explored. The principal installations that make up the project will include: the open pit mine, sterile material dumps, a processing plant (crushing and concentration), a waste material dump, a slime pond, support infrastructure, mining camp, and installations for the concentrate collection and loading in Arica. The project consists of the following principal activities:

- Mineral exploitation using conventional open-pit mining techniques - extraction rates on the order of 220,000 tons of material a month. The transportation of the extracted material from the mine (sterile or mineral) will be performed using trucks with a load capacity of 50 tons. The sterile material will be transported to their final destination at sterile material dumpsites and the minerals will be transported to the feed opening for the primary crusher. The average velocity of the trucks will be 22 km/h, both loaded and unloaded.

- Deposition of sterile material in dumps - During the execution of the Project, a total of two sterile dumps will be constructed. Each dump will have a total storage capacity of up to 30 million tons of sterile material.
- Mechanical preparation of the minerals - size reduction consistent with expectations for a three-stage crushing plant operated in a closed circuit.
- Mineral concentration using dense medium separation methods
- Elimination of the fine fractions by washing - The slurry of extra fine particles removed during the sieving process will then be thickened in order to recover and reuse water and then deposited permanently in a slime pond.
- Transport the final product to a temporary collection yard within the mine – where the product will wait to be embarked by train to their final destination."

According to what is described by this company, this deposit and district would be the greatest known potential for manganese in Chile, found in rocks of a sedimentary-volcanic origin not unlike known deposits in districts of the Coquimbo and Atacama regions.

Notwithstanding the previous facts, it is still necessary to review more information about these projects in the Arica and Parinacota region, in particular with respect to the true viability of exploitation in conjunction with the geological characteristics.

3.3. Potential for manganese ore in tailing deposits

Manganese production in Chile comes exclusively from the Coquimbo region and is performed by small and medium-sized companies dedicated to this labor. No production has been registered since 2010 (CAMCHAL, 2015).

Over 150 Mn minerals are known, where the principal ore minerals are (Mn in %): pyrolusite MnO_2 (55 - 63), braunite Mn_2O_3 (60-69), hausmannite $Mn.Mn_2O_4$ (65-72), manganite MnOOH (50-62), vernadite $MnO_2.nH_2O$ (40-45), psilomelane $MnO.MnO_2$ (40-60), rhodochrosite $MnCO_3$ (40-45), Manganocalcite $(Ca,Mn)CO_3$ (7-23) and manganosiderite $(Mn,Fe)CO_3$ (23-32) (Vasallo, 2008). According to the types of deposits and their possible origins in Chile, manganese minerals, including pyrolusite, rhodochrosite, braunite, and manganite, have been reported in precious metals epithermal deposits; in copper porphyry deposits, and in strata-bound copper deposits. Given that these minerals are considered gangue in all of these deposits, they end up in the tailings of the large-, medium- and small-scale mining industries.

The minimum required grade for exploitation in primary manganese deposits is greater than 10%, for ores that are easy to concentrate, and greater than 20%, for ores difficult to concentrate (Vasallo, 2008). Given the information presented in the state-of-the-art review of tailings deposits in Chile (Proyecto CORFO Valorización de Relaves; Caraballo et al., 2017) and from geochemical data found in databases published by SERNAGEOMIN concerning tailings deposits (Catastro Relaves 2016), the Zorrito deposit in the Petorca community, located in the Valparaiso region, presents a concentration of 6.74% MnO. It is an active deposit with a mass tonnage measuring 72,000 t. Taking into account the fact that the rock has already been subjected to crushing and milling, it is only necessary to determine the mineral occurrence of manganese and the metallurgical viability for its recovery. In spite of the fact that the concentration is lower than those established for the minimum ore grades for Mn exploitation, it would be interesting to evaluate the extraction potential for this element.

Although no other tailings in Chile with high manganese concentrations stand out, the manganese oxide and hydroxide occurrences in the national copper and gold deposits should be examined as a potential secondary source for this metal. In this case, it would be a by-product whose recovery could be evaluated within the main chain of production or, perhaps, during recovery, along with other minerals/elements of value from tailings piles.

4. Selection and description of historically-exploited districts and/or those districts with potential for Co and Mn exploitation

This chapter describes information of the districts selected because of their greater potential for the exploration, evaluation and eventual exploitation of cobalt and manganese. The districts that were visited and sampled, incorporate the results of the studies conducted previously, obtained from the report of samples gathered during the study of potential resources of Co and Mn in Chile (Townley et al., 2017b), and are complemented with the later on-site studies carried out (October 2017).

4.1. Districts with Cobalt as primary ore or as potential by-product

Historically, the exploitation of cobalt in Chile was developed intermittently between 1844 and 1944. The exploited zones include the Tambillos district of the Coquimbo region, the Río Maipo valleys and the El Volcán river of the Metropolitan region, the San Juan district to the south of Freirina, and the Sierra Ladrillos and Los Loros districts in Copiapó (D'Aubarede, 1969; Cruzat, 1968).

The districts that have become the most developed are the San Juan and Tambillos districts. Additionally, there exists a series of deposits widely distributed in environments associated with the metallogenic province of the Coastal Mountain Range in the Atacama and Coquimbo regions that have values for cobalt content similar to those reported in the hypogene zones in the deposits of the San Juan district south of Freirina (Lacassie et al., 2016).

4.1.1. San Juan District

4.1.1.1. Antecedentes

The access to this district is through the road that connects the city of Vallenar with Huasco (C-462) detouring south from Freirina on road C-494 that connects the localities of Freirina and Quebradita, crossing through the Totora and Arco Mollea slopes (Fig. 4.1).

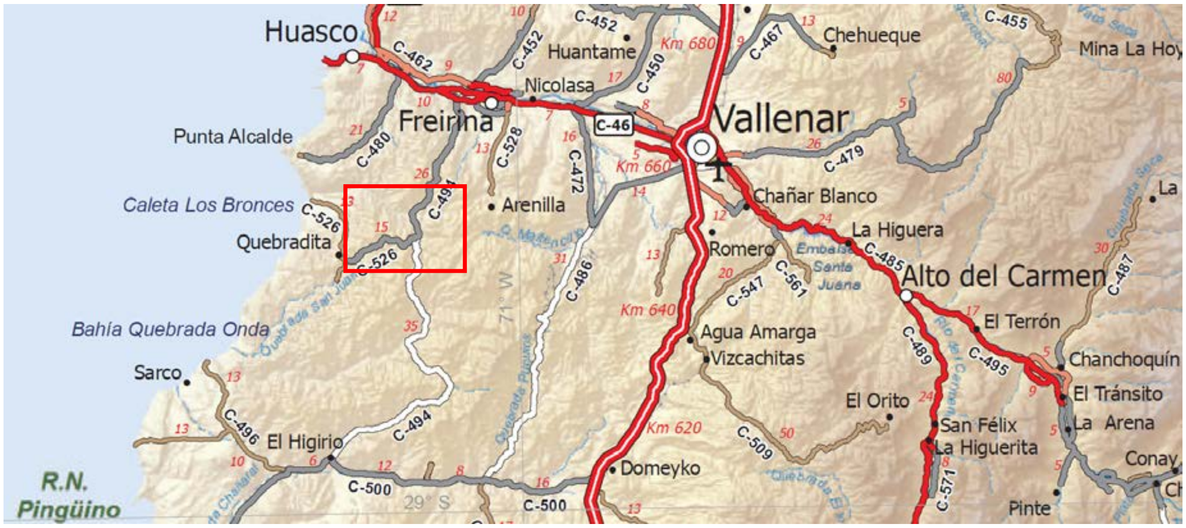


Figure 4.1: Location map and access to the San Juan Mining District (red rectangle).

According to reports by Geoexploraciones (1983), the district of San Juan covers an elongated area oriented in northeasterly direction, over an area measuring 5x10km, and contains 118 vein-body deposits grouped as Minerals Fraguita, El Romero, Cobaltera, Quebradita, and Labrar (Fig. 4.2).

The veins in this district are located both in Paleozoic basement rocks (**Psm**; Fig. 4.3) and in intrusive rocks that cut the basement (**Jmsg, Kig**; Fig. 4.3). When they are located in the intrusive bodies, they generally are associated with dikes and faults oriented in the NW and NNE direction. The basement consists principally of quarziferous metasandstones, metapelites, quartz and micaceous schists, and metabasalts; the intrusive bodies include quarziferous amphibole and biotite diorites that change into quarziferous amphibole and biotite monzodiorites confirmed to exist within the San Juan quarziferous diorite unit (ca. 174 Ma, Welkner et al., 2006, **Jmsg**; Fig. 4.3). The ensembles of previously-described rocks are intruded to the west by plutonic rocks of the Infiernillo Pluton Complex (131-129 Ma, **Kig**; Fig. 4.3). The contact presents a mylonite zone belonging to the western branch of the Atacama Fault System (AFS), developed both in the basement and in the intrusive rocks, with the exception of the San Juan quarziferous diorite where no mylonites are present. In structural terms, the metasedimentary basement presents polyphasic deformation of variable intensity (Fig. 4.3).

Vein orientations have been measured at: NS (+-10°), N25-50E (occasionally N70E-EW) and N40W; they dip in orientations oscillating from subvertical to 50°W; they vary from 0.7 to 4.0 m wide; and they extend over distances of 80 m to 1000 m. The mineralogical composition of the primary ore rock consists of: pyrite, cobaltite, pyrrhotite, chalcopyrite and skutterudite, while the oxidized zone measuring approximately 30 m deep, presents chrysocolla, malachite, azurite, antlerite, erythrite and black cobalt oxides. The mineralogical composition of the gangue includes tourmaline, calcite and quartz. Normally, country rock alteration includes tourmaline and quartz - sericite (Vivallo et al., 2008; Geoexploraciones, 1983; Díaz et al., 1981).

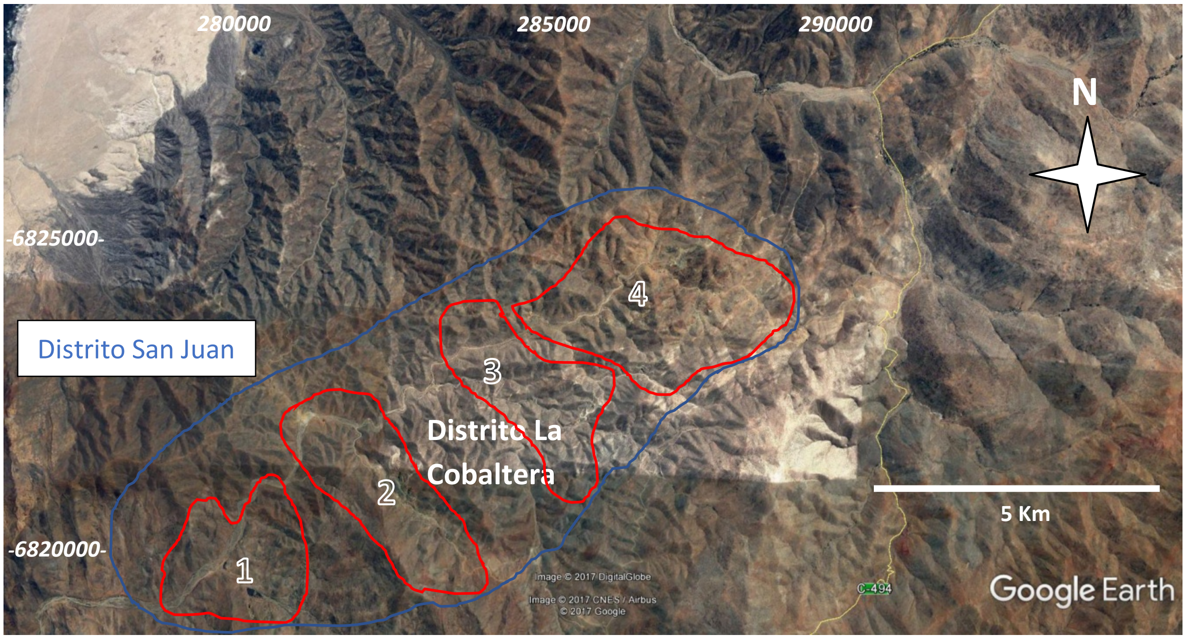


Figure 4.2. Minerals Labrar (1), Quebradita (2), El Romero (3), Fraguita, and the La Cobaltera district in the area of the San Juan district, according to Geoexploraciones (2003).

The results of chemical analyses done on samples of hypogene ore from waste rock, crushed rock and veins in the San Juan district gives a cobalt content varying from 0.001% to 1.95%. Also present are variable amounts of copper (7.9% - 0,037%), gold (1.1 g/t to 0,1 g/t), silver (8.8 g/t to 0.5 g/t), nickel (0.49% to 0.023%) and cadmium (4.7 g/t to 0.023 g/t) (Geoexploraciones, 1983).

Based on their studies, Geoexploraciones recommended 2 favorable zones for the exploration and development of mining operations for the exploitation of cobalt. In order of importance, they are: (Fig. 4.4):

Zone 1

Includes the Cortadera, Pualita, and Verde sectors (Fig. 4.4) and covers an area of 2 x 4 sq km where cobalt analyses indicate values over 0.5%. The recommended mines for performing detailed surface and mine interior studies are Cobaltera, Prosperidad, Blanca, Verde, Lea, Delirio, and Rosa Amelia.

Zone 2

Includes the Labrar, Quebradita Norte, Romero 2, and Fraguita sectors (Fig. 4.4) and covers an area where cobalt analyses indicate values between 0.1 and 0.5%.

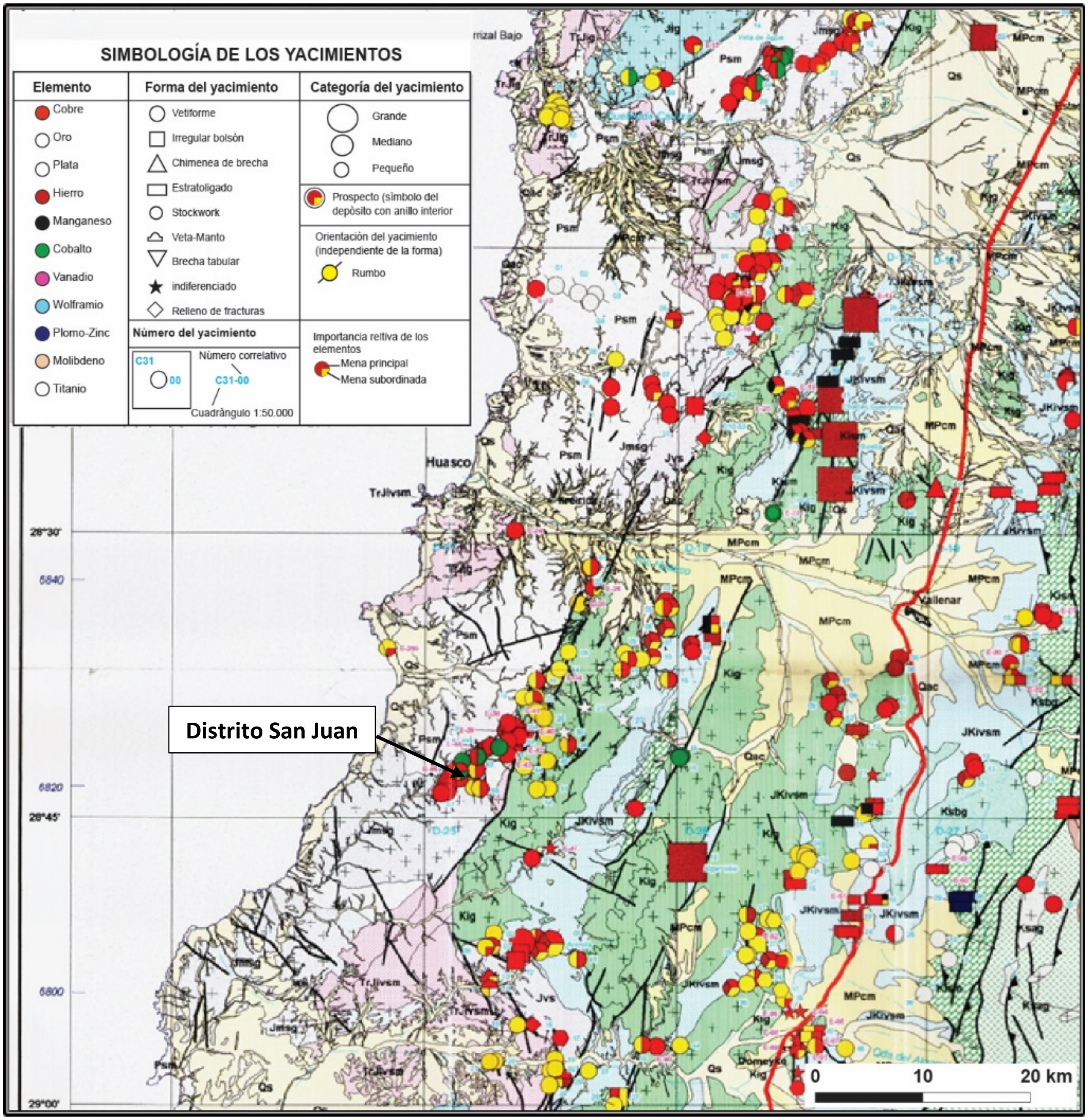


Figura 4.3. Contexto geológico distrito San Juan (tomado de Vivallo et al., 2008: para observación de detalle se recomienda al lector acceder a mapa original).

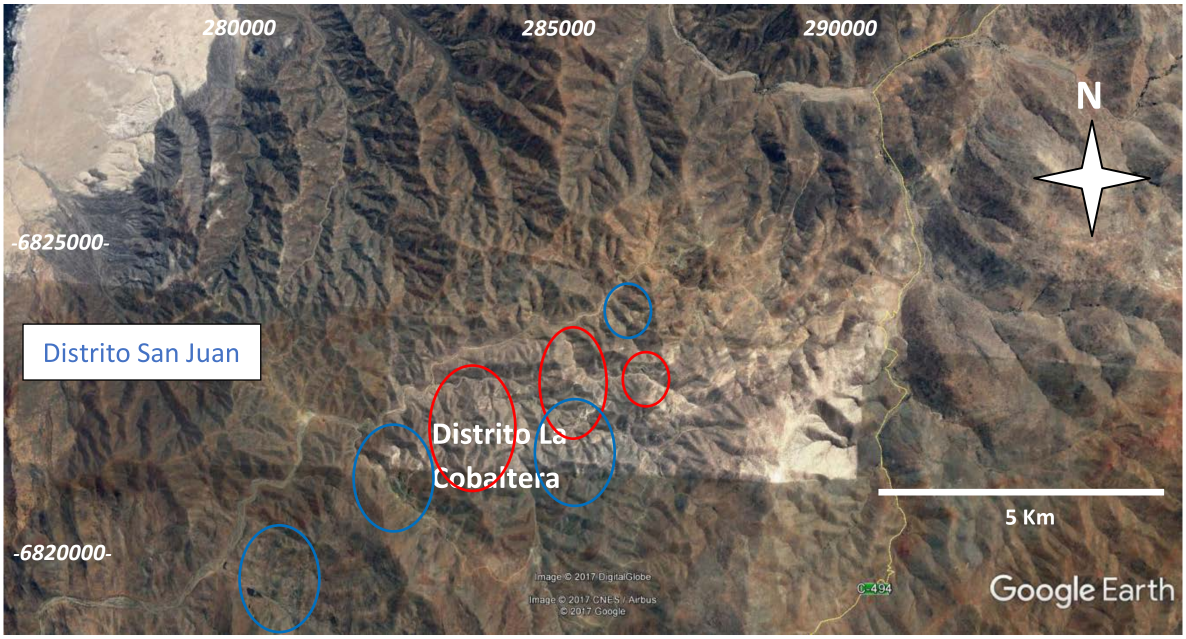


Figure 4.4. Approximate location of the zones of interest: Zone 1 (red) and Zone 2 (blue) in the San Juan district (Geoexploraciones, 1983).

Mineral Resources

Geoexploraciones (1983) indicates 1,300 t of *in-situ* mineral resources, 3,960 t of waste rock with 1% Co in Zone 1, and 62,000 t of waste rock from the Santa Rosa mine (Zone 2) with approximately 0.05 to 0.24% Co and with an average ore grade of 2.44% Cu; all should be sampled and the volume measured.

Additional resources in the order of 500,000 mt of tailings have been reported by Cía. Minera Santa María de Astillas (INTEC, 1988). These are located in the Astillas district, to the north of the city of Freirina, with reported values of 0.11% Co and 0.23% Cu. The same report also mentions other tailings in the areas of Freirina, where hand-collected samples from near the surface gave Co values between 221 and 358 mg/kg, and 80,305 mt of tailings are reported specifically in the Capote Aurífero zone, with Co values from surface samples between 325 – 426 mg/kg.

4.1.1.2. Revision and sample collection at the site

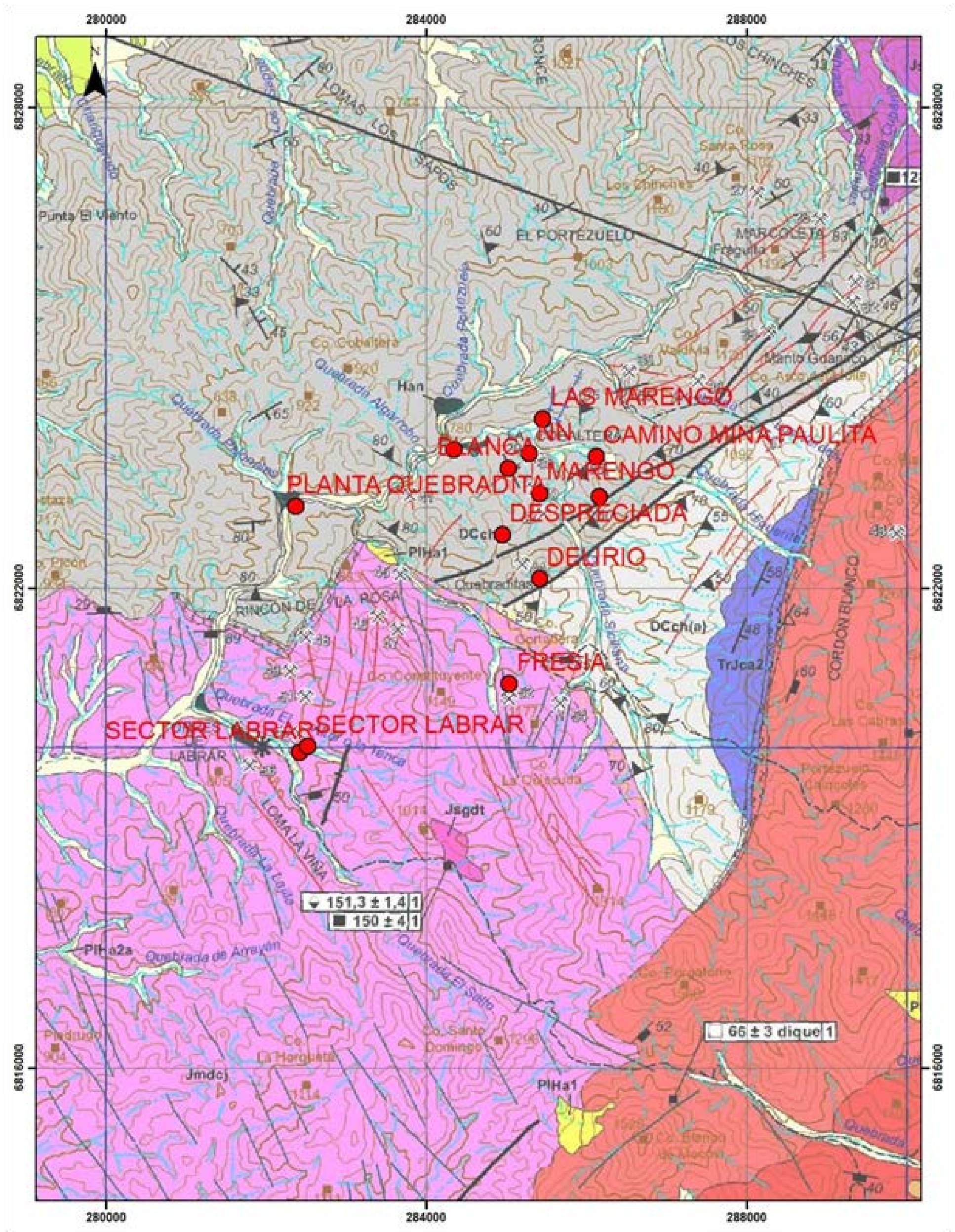
At the San Juan District, at the visiting and sampling collection site, the local geology consists of a basement formed by the Complejo Epimetamórfico Chañaral DCch (Lower Devonian – Carboniferous), a group of metasedimentary rocks which includes sequences of marbles, metacherts and pillow lava metabasalts. This bedrock is intruded by the Infiernillo Plutonic Complex to the east and by San Juan Quartz Diorite to the south (Fig. 4.5).

In terms of lithology, quarciferous meta-sandstones are predominant, which are partly microconglomeradic with angular to sub-rounded clasts, and metapelites; these latter present albite, white mica and chlorite. Also present are the quartz-micaceous schists, metabasites (in part albite green nodular schists) and, in a much smaller proportion, marbles and rocks composed of tremolite, partly asbestiform. In the eastern zone, the quartz-micaceous schists present andalucite, sacaroidal quartz, clinopyroxene and wollastonite. To the western border of this section scarce amphibole is present (DCch (a); Fig.4.5). Overlying these rocks, along an angular discordance on the east border of the sampling area, lie rocks of the Canto del Agua Formation (TrJca; Anisic – Sinemurian), a marine sequence which includes clastic and volcanic sedimentary rocks, formed by conglomerates and arkosic sandstones, shales and limestones, with intercalated rhyolite tuffs and basalts. In the study zone the Middle Member of this formation outcrops (TrJca2; Fig. 4.5), and is formed by metric-scale medium to fine decreasing grain-size matrix supported conglomerates, with centimetric size felsic lithic clasts, medium to thick quartz-feldspars sandstones and medium to fine lithoarenites and shales.

On the south zone of the district the metamorphic basement is intruded in a subvertical manner with a slight inclination to the north, by the San Juan quartz diorite Jmdcj (ca. 174 Ma; Fig. 4.5), that corresponds to a body of quartz-diorite to diorite composition, characterized by amphibole-quartz and medium grain biotite monzodiorites with lithologic variations to amphibole and piroxene diorites and amphibole – biotite quartz monzodiorites. The rocks appear to be altered, with mafic minerals partially replaced by chlorite and/or actinolite, and argillic altered feldspars. It outcrops continuously from north of Quebraditas to south of the Torrejón Mountain.

On the north zone of the study area the La Arena monzodiorite Jsma (ca.157 Ma; Fig.4.5) outcrops, and limits to the west with metasedimentary rocks of the Complejo Epimetamórfico Chañaral (DCch), along a belt of milonites. Petrographically the plutonic rocks are composed of inequigranular quartz monzodiorites with larger crystals of plagioclase, piroxene, amphibole and piroxene and amphibole pseudomorph biotite. The population of minor crystals is composed of quartz, plagioclase, orthoclase, biotite, amphiboles and recrystallized piroxenes. The accessory minerals are apatite, sphene, zircon and tourmaline.

The La Totora granodiorite Jsgdt (152-151 Ma; Fig. 4.5) outcrops west of the sampling area, an intrusive granodiorite of small dimensions (<16 km2) that outcrops along the mountain chain of La Totora, between the La Salvia and Agua Salada creeks. Petrographically, the pluton is composed of biotite granodiorites and amphibole and in a lesser proportion, amphibole and biotite monzogranites, with apatite, sphene and zircon as accessory minerals. The mafic minerals are moderately altered to prehnite, chlorite, muscovite and titanite. There exists satellite bodies of granodiorites, with biotite and amphibole slightly altered to chlorite and epidote (Fig. 4.5).



DCch ▨ (a) **Complejo Epimetamórfico Chañaral** (Devónico-Carbonífero Inferior) Metaareniscas cuarcíferas, en parte microconglomerádicas, con clastos angulosos a subredondeados y metapelitas; estas últimas portadoras de albita, mica blanca y clorita. **(a)** Esquistos cuarzo-micáceos, metabasitas (en parte esquistos verdes nodulares de albita) y, en escasa proporción, mármoles y rocas compuestas por tremolita, en parte asbestiforme.	**TrJca** ▨ (3) (2) (1) (2b) (2a) **Formación Canto del Agua** (Anísico-Sinemuriano) Secuencia sedimentaria marina, clástica y volcánica, formada por conglomerados y areniscas arcósicas, lutitas, calizas con tobas riolíticas y basaltos intercalados. **(2)** Conglomerados medios a finos, matriz soportados, con clastos líticos ácidos centimétricos, areniscas cuarzo-feldespáticas medias a gruesas y litoarenitas medias a finas y lutitas fisibles.
Jmdcj ▨ **Diorita Cuarcífera San Juan** (*ca*. 174 Ma) Dioritas cuarcíferas de anfíbola y biotita de grano medio, con variaciones a monzodioritas cuarcíferas de anfíbola y biotita. En general, los máficos se presentan reemplazados a clorita y/o actinolita y los feldespatos argilizados.	**Jsma** ▨ **Monzodiorita La Arena** (*ca*. 157 Ma) Monzodioritas cuarcíferas inequigranulares de plagioclasa, piroxeno anfíbola y biotita seudomorfa de piroxeno y anfíbola.
Jsgdt ▨ **Granodiorita La Totora** (152-151 Ma) Granodioritas de biotita y anfíbola y, en menor proporción, monzogranitos de anfíbola y biotita. Presenta dos cuerpos satélite granodioríticos.	**Kii** ▨ (gd) (d) **Complejo Plutónico Infiernillo** (131-129 Ma) **(gd)** Granodioritas, tonalitas y escasas monzodioritas cuarcíferas de anfíbola, biotita y piroxeno. Presentan ocasionalmente texturas porfídica a poikilítica y rasgos de deformación cristaloplástica, fracturamiento, dislocación y recristalización de minerales **(d)** Dioritas y dioritas cuarcíferas de grano medio a fino, con anfíbola y piroxeno como máficos principales. Localmente, presenta notables signos de deformación cristaloplástica, con recristalización y probable introducción y/o neoformación de cuarzo.

Figure 4.5: Modified geological map of the Freirina – El Morado region, 1:100.000 (Welkner et al., 2006). The names indicate the mineral processing plants or mines from where the samples were obtained.

On the east part of the area outcrops the infiernillo Plutonic Complex Kii (131-129 Ma; Fig. 4.5), that corresponds to the plutonic group with the largest exposition surface in the region (ca. 320 km2). It is composed of granites and diorites distributed in a 40 km long northeast outcropping belt, from the Cordón de Ossandon, in the south, to the Llanos de Arenilla, in the north. Lithologically the basal subunit (Kii (gd); Fig. 4.5) is composed of granodiorites, tonalites and scarce quarz monzodiorites, with amphibole, biotite and pyroxene as the main mafic minerals. Apatite is is present as an accessory mineral. This plutonic complex limits to the west with volcanoclastic and volcanic rocks of the Canto del Agua Formation and with metamorphic rocks of the Complejo Epimetamórfico Chañaral, along a milonitic and synplutonic migmatite belt which are part of the Infiernillo Shear Zone, a zone of ductile deformation 63 km long, which has been described as the most occidental branch of the Atacama Fault System in the Province of Vallenar (Arévalo et al., 2003; Fig. 4.5).

Sample collection at the San Juan District

During the inspection visits to the San Juan District a total of 19 samples were obtained, 15 of which are from the mine stripping sites and 4 from the surrounding areas of the material processing plants. The location of samples and their origin are indicated in Table 4.1 and Figure 4.5.

Table 4.1: Summary of the samples gathered at the San Juan Mining District. The samples associated to the processing plants La Cobaltera and Quebradita are highlighted in yellow.

CORRELATIVO	UTMN PSAD 56	UTME PSAD 56	UTMN WGS 84	UTME WGS 84	CODIGO MUESTRA	DISTRITO	MINA
1	6820804	285033	6820469	284833	Mina Fresia 1_5	SAN JUAN	FRESIA
2	6822663	284946	6822328	284745	Mina Despreciada	SAN JUAN	DESPRECIADA
3	6823182	285408	6822847	285207	Las Marengo-1	SAN JUAN	MARENGO
4	6823182	285408	6822847	285207	Las Marengo-2	SAN JUAN	MARENGO
5	6824110	285453	6823774	285252	Las Marengo-3	SAN JUAN	LAS MARENGO
6	6824110	285453	6823774	285252	Las Marengo-4	SAN JUAN	LAS MARENGO
7	6823143	286157	6822805	285959	Las Marengo-5	SAN JUAN	LAS MARENGO-5
8	6823016	282368	6822680	282168	Planta Relave-01	SAN JUAN	PLANTA QUEBRADITA
9	6823016	282368	6822680	282168	Planta Relave-02	SAN JUAN	PLANTA QUEBRADITA
10	6823016	282368	6822680	282168	Planta Relave-03	SAN JUAN	PLANTA QUEBRADITA
11	6819943	282411	6819608	282211	Sector Labrar-01	SAN JUAN	SECTOR LABRAR
12	6820022	282513	6819687	282313	Sector Labrar-02	SAN JUAN	SECTOR LABRAR
13	6822117	285413	6821780	285150	Mina Delirio-01	SAN JUAN	DELIRIO
14	6822117	285413	6821780	285150	Mina Delirio-02	SAN JUAN	DELIRIO
15	6823731	284340	6823394	284139	Planta La Cobaltera-01	SAN JUAN	PLANTA LA COBALTERA
16	6823681	285284	6823346	285083	Veta NN Qzo-01	SAN JUAN	NN
17	6823493	285025	6823156	284824	Mina Blanca-01	SAN JUAN	BLANCA
18	6823493	285025	6823156	284824	Mina Blanca-02	SAN JUAN	BLANCA
19	6823643	286122	6823308	285922	Sector Paulita-01	SAN JUAN	Camino Mina Paulita

Next we submit a brief description of the areas from where the different samples were obtained, and that are related to small mines, sumps, inclines, surface workings, etc. It is worth mentioning that only samples from the stripping areas were collected, since it was impossible to access the inside of mines, because of the state of abandonment and hazardousness in which they are found.

Fresia Mine (in production): Located within the Quebraditas gorge, between the Constituyente and La Quiscuda hills, rocks of the San Juan Quartz Diorite outcrop here, these described previously. At this location, one sample was collected from a rock pile of vein material, presenting martitic magnetite – quartz – tourmaline, with chalcopyrite, arsenopyrite, bornite, cuprite, chrysocolla, atacamite and antlerite (Fig. 4.6). Identification of sample: Fresia Mine 1_5.

Figure 4.6: Photo of a mineralized structure (left) and samples of rocks obtained from inside of the Fresia mine (right). Green oxidized copper and samples of magnetite with hematite and iron hydroxides are observed

Despreciada Mine (abandoned): Located inside the Quebrada Siciliana, between the Quebraditas area and the homonymous gorge. Rocks from the Complejo Epimetamórfico Chañaral outcrop in this area, these previously described. One sample was collected at this location from a stock pile, observing the existence of erythrite associated with quartz-tourmaline and calcite. Figure 4.7 shows the entrance to this work station, and according to oral information from the local miners, it is approximately 80 to 100m deep. Identification of the sample: Despreciada Mine.

Figure 4.7: Photo of main acces to the Despreciada Mine, which lies abandoned. Behind entrance lies small stockpile of rocks from the veins within the mine.

Delirio Mine (abandoned): Located on the west side of the Quebrada Siciliana at the Cerro Cortadera. In this area rocks from the Complejo Epimetamárfico Chañaral outcrop, these previously described. Here two samples were collected from mineral piles, these from vein rocks of quartz-tourmaline with erythrite-chalcopyrite-pyrite and hydrothermal breccias with manganese oxide matrix. Sample identifications: Mina Delirio-01 and Mina Delirio-02.

Marengo Mine (abandoned): Located at the border of Quebrada Siciliana near the Quebrada Higuerita crossroad. In this area rocks from the Complejo Epimetamórfico Chañaral outcrop, these previously described. Two samples were collected, from mineral piles of veins with quartz-limonite-jarosite and from veins with green oxidized copper and erythrite mineralization, clay, quartz and iron oxides. Sample identifications: Las Marengo-1 and Las Marengo-2.

Las Marengo Mine (in production): Located on the north side of the Quebrada Algarrobo, east of the old plant La Cobaltera, before the bifurcation at the Quebradas Siciliana and Higueritas. In this area rocks from the Complejo Epimetamórfico Chañaral outcrop, these previously described. Mineralization occurs in the form of mantos of variable thickness, with an approximate dip of 35° to the northwest. As seen at the site, it is deduced that the mine is being exploited underground. At this worksite two samples were collected, from mineral piles of veins with quartz-tourmaline, green oxidized copper – black manganese minerals, limonite and jarosite and veins with quartz-tourmaline, erythrite and chalcopyrite-pyrite (Fig.4.8). Sample identifications: Las Marengo-3 and Las Marengo-4.

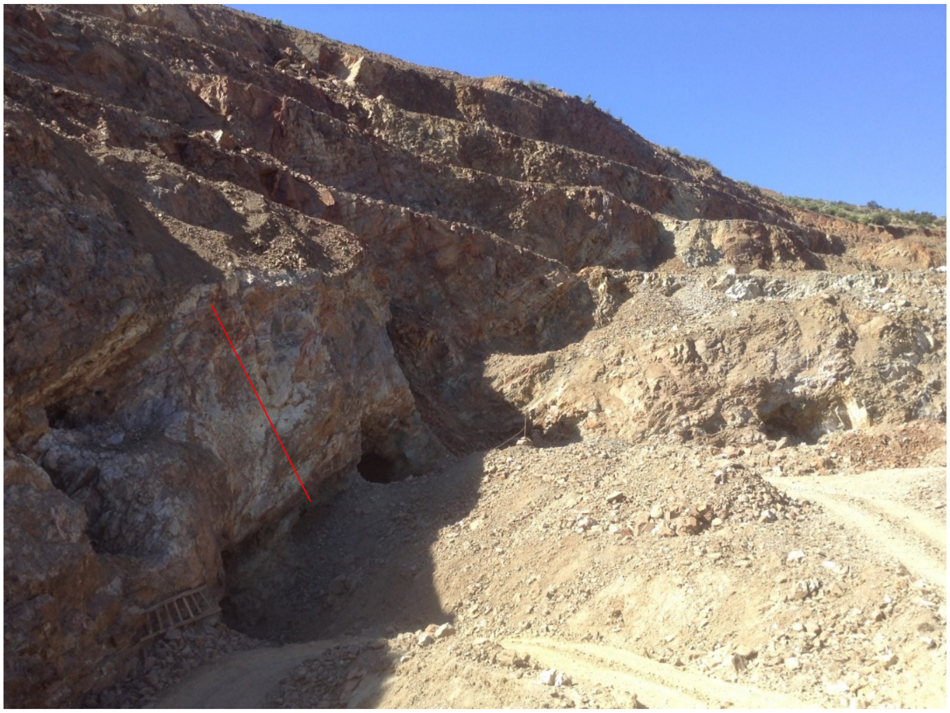


Figure 4.8: Photo of the mineralized manto at the Las Marengo Mine. Specially noted is the mineralized manto with an approximate dip of 35° to the northwest. Red line indicates an estimated thickness of 5 to 10m.

Las Marengo-5 Mine (abandoned): Located on the east border of the Quebrada Siciliana creek, between this creek and the Quebrada Higueritas creek. In this area rocks from the Complejo Epimetamórfico Chañaral outcrop, these previously described. At this site one sample was collected from mineral piles of vein rocks with quartz-tourmaline, biotite (chloritized), chrysocolla, green oxidized copper minerals, and iron and manganese oxides. Identification of sample: Las Marengo-5.

Quartz-NN Vein (abandoned): Located at the Quebrada Algarrobo creek, east of the La Cobaltera plant. In this area rocks of the Complejo Epimetamórfico Chañaral outcrop, these previously described. One sample was collected from the stripping of vein rocks with quartz-tourmaline - jarosite, green oxidized copper minerals and manganese oxides. Identification of sample: NN Qzo-01 Vein.

Blanca Mine (abandoned): located on the west side of Quebrada Algarrobo creek. The rocks that outcrop are from the Complejo Epimetamórfico Chañaral, these described previously. In this old mine two samples were collected from the stripping of vein rocks with quartz-tourmaline, with pyrite and erythrite mineralization, hosted in schist with disseminated sulfides and scarce oxidized copper minerals (Fig. 4.9). Identification of samples: Blanca Mine-01 and Blanca Mine -02.

Figure 4.9: Photos of the Blanca Mine sector. On the right outcropping where iron hydroxides are shown together with green copper oxide minerals, iron hydroxides and argillic altered rocks. Left, sample of rock with erythrite, obtained from the mine stripping.

Paulita Vein Sector: located on the road to Paulita Mine at the Quebrada Higuerita creek. The rocks that outcrop are from the previously described Complejo Epimetamórfico Chañaral. In this sector one sample was collected from a vein with quartz-tourmaline and erythrite and green oxidized copper mineralization. Sample identification: Sector Paulita-01.

Mines at the Labrar Sector (in operation): located at the extreme end of the Quebrada El Altar de la Tenca creek. At this sector, rocks of the San Juan Quartz Diorite, these previously described. At this mine two samples were collected from the stripping of veins with magnetite-quartz-calcite, pyrite-arsenopyrite, and chalcopyrite-clorite-biotite. Identification of samples: Labrar-01 Sector and Labrar-02 Sector.

In addition to the samples collected from the operating mines, 4 samples were also collected from the old abandoned plants, one from the La Cobaltera Plant and three from the Quebradita Plant. These are described hereunder.

La Cobaltera Plant: A sample of leach pad gravels was taken in the immediate surroundings of the La Cobaltera Plant. This sample shows erythrite precipitates and copper sulfates (Fig. 4.10). Identification of the sample: La Cobaltera-01 Plant.

Figure 4.10: Left: General view of the condition of the La Cobaltera Plant: Right: Leach pad gravels from the La Cobaltera plant. The photo shows erythrite precipitates, copper sulfates and gypsum.

La Quebradita Plant: Samples were gathered from the plant tailings, process material (oxidized pyrites) and plant feeding material consisting of veins with quartz-calcite-sericite-chlorite-iron oxides (copper oxides) in intrusive and schists (Fig 4.11).Identification of samples: Planta Relave-01, Planta Relave-02 y Planta Relave-03.

Figure 4.11: Left: La Quebradita Plant Tailings Deposit, material sampled for analysis. Red line indicates an approximate thickness of 4-6 m. Right: General view of the Quebradita Plant.

4.1.1.3. Prospective geochemical results for the San Juan District

The rock samples collected at the San Juan Mining District, obtained mainly from mine strippings and mineral piles from mine shafts and open pit extractions, were analyzed through an Aqua Regia Digestion and ICP-OES analysis (AQ370, BUREAU VERITAS MINERALS LABORATORIES) for a total of 24 elements (Table 4.2).

Table 4.2: Elements analyzed through an Aqua Regia Digestion and ICP-OES reading; unit: report unit and lower detection limit (LDL).

Elemento	**Mo**	**Cu**	**Pb**	**Zn**	**Ag**	**Ni**	**Co**	**Mn**	**Fe**	**As**	**Sr**	**Cd**
Unidad	%	%	%	%	GM/T	%	%	%	%	%	%	%
LDI	0,001	0,001	0,01	0,01	2	0,001	0,001	0,01	0,01	0,01	0,001	0,001
Elemento	**Sb**	**Bi**	**Ca**	**P**	**Cr**	**Mg**	**Al**	**Na**	**K**	**W**	**Hg**	**S**
Unidad	%	%	%	%	%	%	%	%	%	%	%	%
LDI	0,001	0,01	0,01	0	0	0,01	0,01	0,01	0,01	0	0,001	0,05

Geochemical results obtained from mines, mine shafts and mineral workings

Of the chemical results from the different samples collected mainly from mine stripping material from mine shafts and open pit extractions, it is worth mentioning that the values of cobalt in this zone are between 0.005% and 0.789%, 5 of which showed values of over 0.1% Co (Table 4.3). In most of the samples collected the reported values for copper are over 0.5%, 7 of which show over 1% Cu. One sample stands out with a value over 10% Cu and 0.087% Co (Fresia Mine 1_5) (Table 4.3). The values of Mn in the samples are low. The values of iron show 5 samples with over 10% (maximum 31.54%), associated mainly to stripping samples of veins with presence of magnetite. In several samples the values of As exceed 0.1% (9 samples, Table 4.3). The sulfur concentration in the samples presents values that exceed 0, 1% S in several of them, reaching a maximum value of 16.36% S, associated to a concentration of 23.07% Fe, 2.136% of Cu and 0,085% Co (sample Labrar Sector- 01, Table 4.3).

The chemical results are related to the type of stripping material collected which are mainly, veinlets, veins, breccias, with the following minerals: magnetite, quartz, tourmaline, chalcopyrite, bornite, pyrite, arsenopyrite, cuprite, atacamite, antlerite, limonite, jarosite, and cobalt minerals such as erythrite and cobaltite, among others (Table 4.3).

In reference to the geochemical results reported by Geoexploraciones (1983) the following is a comparative analysis with the results of this present study:

Despreciada or Cobaltera Mine: The mine is hosted along a 100 m long structure with a N20°E strike and a dip of 70°W, having an average thickness of about 2 m. In the mine stripping area there are rock piles of silicified schists with cobaltite and erythrite without copper oxides. Eight different samples collected at the stripping areas and at the mine, showed ranges from 0.28 to 1.81% Co and 0.004 to 0.006% Co. These results match the results of the chemical analysis obtained from the one sample collected in this study (Mina Despreciada sample, Table 4.3). Access inside the mine was not possible due to safety reasons.

Rosa Amelia Mine (Marengo Mine, Samples: Las Marengo 1 and 2 in this study). Vein that runs along strike for 500 meters, oriented N5°E, N10°E, N15°E, with dips of 55°W – 40°W – 30°W. To the south average thickness is close to 1 m and to the north 2 m. The mineralization occurs within a tourmaline – quartz vein. The surface shows azurite, malachite and black oxides. It is hosted in schists and was exploited for copper. The results of this study, with values of Cu between 1 and 1.3% and Co between 0.05 and 0.278% (Table 4.3) match the concentration levels indicated by Geoexplorations (1983) and confirm this sector to be one of top priority interest.

Table 4.3: Analytical Results for Co, Cu, Mn, Fe, As and S. The other elements in Annex 2: Name of the Mine, mine shafts and pits and summary of the sample description.

Muestra	Co %	Cu %	Mn %	Fe %	As %	S %	MINA	DESCRIPCIÓN - MUESTRA
Mina Fresia 1_5	0,087	>10,000	<0,01	31,54	0,08	1,02	FRESIA	Desmontes: vetas de Mgt(Mar)-Qzo-Turm-Cpy-Arspy-Bor-Cup-Cris-Atac-Antl
Mina Despreciada	0,416	0,054	0,02	3,98	0,59	0,26	DESPRECIADA	Desmontes con Eritrina asociada a Qzo-Turm (Cal)
Las Marengo-1	0,278	1,333	0,01	6,7	0,71	0,05	MARENGO	Desmonte: vetas de Qzo-Lim-Jar
Las Marengo-2	0,049	1,062	<0,01	23,68	0,23	0,06	MARENGO	Desmonte: vetas Ox.Cu-Eri-Arc-Qzo-Ox.Fe
Las Marengo-3	0,079	2,967	0,06	10,25	0,1	<0,05	LAS MARENGO	Desmonte: vetas de Qzo-Turm-Ox.Cu-Ox.Mn-Lim-Jar
Las Marengo-4	0,443	0,683	0,03	3,5	0,77	<0,05	LAS MARENGO	Desmonte: vetas de Qzo-Turm-Eri-Cpy-Py
Las Marengo-5	0,017	1,618	0,03	6,17	0,12	<0,05	LAS MARENGO-5	
Sector Labrar-01	0,085	2,136	0,04	23,07	<0,01	16,36	SECTOR LABRAR	Desmonte: vetas de Mgt-Qzo(Cal)-Py(Arspy)-Cpy-Clo-Bt
Sector Labrar-02	0,015	2,379	0,05	9,15	0,02	3,41	SECTOR LABRAR	Desmonte: vetas de Mgt-Qzo(Cal)-Py(Arspy)-Cpy-Clo-Bt
Mina Delirio-01	0,781	0,302	0,03	1,84	1,19	0,26	DELIRIO	Desmonte: vetas Qzo-Turm-Eri-Cpy-Py
Mina Delirio-02	0,1	0,974	0,02	21,03	0,18	<0,05	DELIRIO	Desmonte: brecha matriz de Ox.Mn
Veta NN Qzo-01	0,022	0,271	0,01	2,41	0,06	<0,05	NN	Desmonte: veta Qzo-Lim-Jar-(Ox.Cu-Ox.Mn)
Mina Blanca-01	0,649	1,561	0,01	4,9	1,07	0,82	BLANCA	Desmonte: veta Qzo-Turm-Py-Eri
Mina Blanca-02	0,021	0,662	0,02	3,39	0,1	<0,05	BLANCA	Desmonte: esquistos con sulfuros diseminados y escasos minerales Ox.Cu
Sector Paulita-01	0,005	0,601	0,01	3,74	0,02	<0,05	Camino Mina Paulita	Desmonte: veta Qzo-Turm-Eri-(Ox.Cu)

Qzo: Quartz; Turm: Tourmaline; Cal: Calcite; Mgt: Magnetite; Mar: Martite; Cpy: Chalcopyrite; Arspy: Arsenopyrite; Bor: Bornite; Py: Pyrite; Cup: Cuprite; Cris: Chrysocolla; Atac: Atacamite; Antl: Antlerite; Eri: Erythrite; Lim: Limonite; Jar: Jarosite; Clo: Chlorite.

Blanca Mine: consists of an extraction shaft and other inaccessible auxiliaries and is located in a vein that strikes N30°E with a dip of 50°W, reaching a thickness of 3 m. This vein is associated with a fault that together reaches a thickness of about 3 to 4 meters. It is composed of tourmaline and quartz intercalated within milonitic deformed schist. There is abundant malaquite, chrysocolla, atacamite; azurite and black oxides and the mine stripping materials contain erythrite. A sample collected from the mine stripping piles during the study made by Geoexploraciones (1983) indicated 0.24% Co, similar to the range determined in this study (Samples Mina Blanca-01 and Mina Blanca-02, Table 4.3).

Delirio Mine: The Delirio Mine is located within a vein of N10°E to N10°W strike, with an average thickness of 4 m, extending 150 to 180 m along strike. The vein is hosted by schists, next to andesitic dikes and a fault. In the area of the fault there are milonites, altered schist and a vein with quartz-tourmaline of 1, 0 to 1, 5 m thickness. There are copper oxides in less quantity and abundant disseminated erythrite. The samples obtained during the study done by Geoexploraciones (1983) show a result of 0.5% to 0.54% cobalt and 1.13% copper; those results are similar to the ones obtained in this study (Samples Delirio-01 Mine and Delirio-02 Mine, Table 4.3).

The mineralization in the district of San Juan is found mainly in the form of limited thickness veins not exceeding a few meters, with Co grades of up to 0.78% and copper in ranges over 1%, including one particular case that was over 10% (Table 4.3). The majority of the mining deposits visited show the development of an oxidation zone of variable proportions evidenced through the direct observation and/or inferred by the type of material that is present in mine stripping rock piles, where erythrite predominates together with iron hydroxides and green oxidized copper minerals. These oxidations zones extend to depths of about 30 to 40 m. The maximum depth reached during past exploitation is in the order of 100 m. In these zones a local secondary enrichment could occur, with an increase of the mineral grades to concentrations between 6 to 8% of Co, this based on historical records.

The results from the geochemical analysis in this study corroborate the results reported by Geoexploraciones (1983) and the historical data, thus confirming the presence of cobalt in all of the area that was visited, as well as high concentrations of copper determined in most of the samples. At present there are exploitation activities for the production of copper in this district, ore rocks shipped to the ENAMI plants in Vallenar. There is no report regarding the recovery of cobalt.

Geochemical Results of samples collected at the Quebradita and Cobaltera plants

The samples collected at the San Juan Mining District obtained from the Quebradita and the La Cobaltera plants, were analyzed by means of Aqua Regia Digestion and ICP-OES analysis (AQ370, BUREAU VERITAS MINERALS LABORATORIES) for a total of 24 elements (Table 4.2).

The higher concentrations of Co in the different samples collected from the plants are present in the leach pad gravel samples from the La Cobaltera plant and in the plant supply samples at the Quebradita plant, with values of 0.211% and 0.189% of Co respectively (Samples Planta La Cobaltera-01 and Planta Relave-03, Table 4.4). It is worth mentioning that the report of these samples showed high concentrations of copper, 3.765% for the Quebradita plant and 1.223% for the Cobaltera plant, as well as values over 0.19% As for both samples (Table 4.4). In general the concentration of iron in the samples is high, over 8% (Table 4.4).

Table 4.4: Analytical Results for Co, Cu, Mn, Fe, As and S from samples obtained from the Quebradita and Cobaltera plants. Other elements are presented in Annex 2. Name of mine shaft or pit working areas and summarized description of samples.

Muestra	Co %	Cu %	Mn %	Fe %	As %	S %	Planta	DESCRIPCIÓN - MUESTRA
Planta Relave-01	0,011	0,564	0,06	9,21	0,02	0,79	PLANTA QUEBRADITA	Relave
Planta Relave-02	0,012	0,89	0,01	22,51	0,01	11,59	PLANTA QUEBRADITA	Piritas oxidadas
Planta Relave-03	0,189	3,765	0,13	10,14	0,29	5,86	PLANTA QUEBRADITA	Vetas de Qzo-Cal-Ser-Clo-Ox.Fe-(OxCu) en intrusivo y esquistos de alimentador planta
Planta La Cobaltera-01	0,211	1,223	0,05	8,36	0,19	1,19	PLANTA LA COBALTERA	Ripios

Qzo: Quartz; Cal: Calcite, Ser: Sericite; Clo: Chlorite

All analytical results of the samples taken during the visit to the different mine work sites and deposits at the San Juan District confirm the high potential for cobalt and copper. It is important to mention though, that the highest potential of the two stands for copper, aspect which cloaks the existence of cobalt, allowing economic exploitation of these deposits only for copper ore. It becomes necessary to focus on studies and evaluation for a combined exploitation of copper and cobalt to maximize the eventual benefits of the existing mines and deposits in this district.

4.1.2. Tambillos District

4.1.2.1. General information

The Tambillos district is found in the Andacollo community, approximately 33 km to the south of the city of La Serena, and covers a surface area of approximately 40 km2 (Fig. 4.12). The district is accessed via a route connecting La Serena with the city of Ovalle. The Tambillos district is contained in the Arqueros metallogenic domain (D3A), defined in the area shown on the map Yacimientos Metalíferos del Área de Andacollo – Puerto Aldea (Metalliferous deposits for the Andacollo – Puerto Aldea Area) (Díaz et al., 2010) (Fig. 4.12).

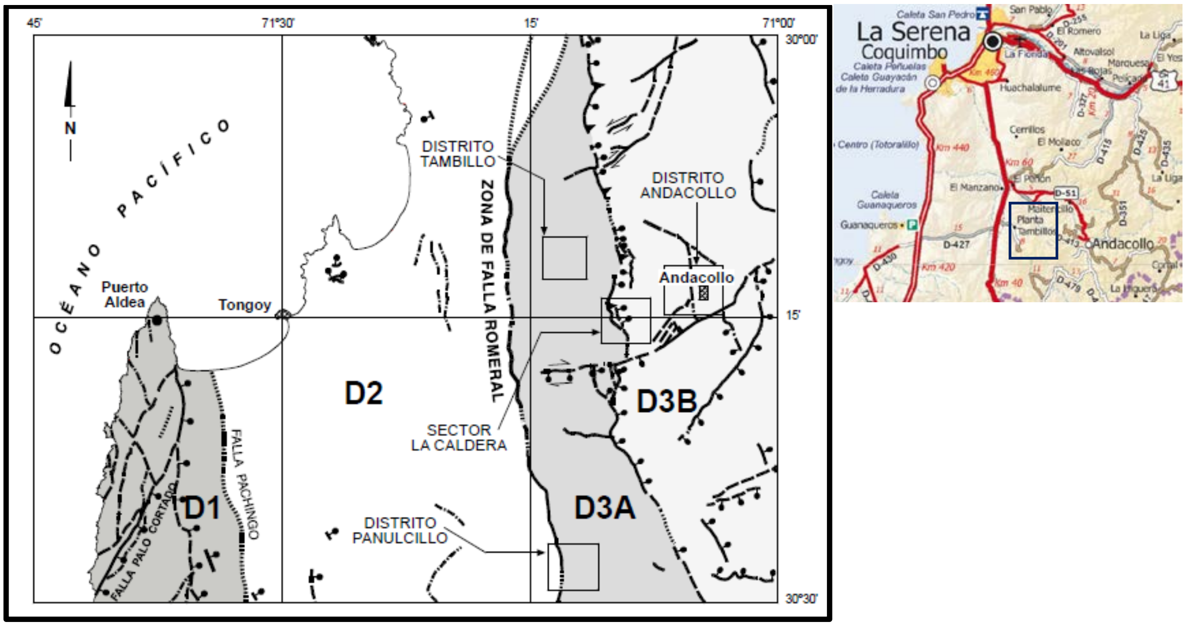


Figure 4.12. Metallogenic context of the Tambillo district (taken from Díaz et al., 2010)..

The deposits in the district include IOCG-type vein deposits hosted in intrusive rocks of Lower Cretaceous age (122-120 Ma, **Kig1**; Fig. 4.13) and in hypabyssal bodies of early Upper Cretaceous age (**Ksbg**; Fig. 4.13), as well as within stratified volcanic and sedimentary rocks of Upper Jurassic – Lower Cretaceous age (Arqueros Formation, **JKvs**; Fig. 4.13), and strata-bound IOCG-type deposits contained in the same litho- and chronostratigraphical layers at the base of the volcanic-sedimentary sequence of the Arqueros Formation. All of these rocks and deposits described here are distributed to the west of the Romeral Fault System (RFS) and have been affected by an intense contact metamorphism associated with the emplacement of granodiorites, granites, and diorites (122 – 120 Ma, **Kig1**; Fig. 4.13) located in the central zone of the district. The volcanic rocks include basaltic andesites, hyaloclastites, and peperites. Concordantly above these rocks are amphiboles which in turn are overlain by a partially brecciated garnetite, both of these rock units host, along tens of kilometers, to discrete strata-bound mineralization. Above the mineralized amphibole and garnetite rocks, stratified silicified rocks are present, the protolith of these rocks being limestone and subordinate sandstone with intercalated chert, shale and tuff. The above-described sequence is found intruded by a series of aphanitic and aphyric dikes, porphyritic andesites, and hypabyssal andesitic-basaltic bodies from the Late Lower Cretaceous – Early Upper Cretaceous. The deposits exploited for cobalt, specifically those found in the Buitre and Minillas mines, belong to a strata-bound manto like deposit. The mineralized manto bodies have a strike between N15-35°W, and dip from 45 to 55°W. The manto bodies are conformed by a hornfels with trace recrystallized actinolite and calcite together with abundant interstitial chlorite. The floor wall is a meta-andesite which presents a potassic alteration characterized by the presence of biotite and potassium feldspar; the roof wall is composed of chert layers. The mineralogical composition of the primary ore includes: chalcopyrite, pyrite, arsenopyrite, sphalerite, galena, cobaltite, and tetrahedrite in addition to trace amounts of erythrite in the surface oxidation zones. Cobaltite is described to occur, principally, in the contact zone between the mineralized manto and the hanging wall (chert) and, to a lesser extent, disseminated as coarse-grains in the interior of the manto like body along with the other mentioned sulfides.

The greatest development in relationship to cobalt exploitation is the Buitre mine deposit, which in 1975 was exploited from three mine levels; the height between each level is 20m. The upper level is a gallery that measures 200m long, 4m wide, and 30m tall. Mineral exploitation in the upper level began from a pit which is 170m long, 4m wide and 15m tall. The lower intermediate level is comprised of a gallery measuring 50m long, and the lowest level is comprised of a gallery measuring 30m long. It is estimated that at the time the average cobalt ore grade was around 1% and that ore rock was extracted at a minimum average of 0.46% Co. The Minillas mine, operating at the same time as the Buitre mine, presents the same characteristics and is currently being prepared to exploit zones with remnant oxidized copper minerals. The only medium-scale mine is the Florida mine, which operated at the same time as the Buitre – Minillas mines and also presents similar characteristics. Currently, it is being mined to recover, principally, copper. The materials, processed in a plant within the district, have generated a significant volume of tailings.

The deposits found in the northern portion of the district occur in veins oriented preferentially N60E/80SE; they measure up to 300m long, are between 0.4 and 1.0m wide, and go no less than 300m deep. Mineralization is indicated by the presence of magnetite, pyrite, arsenopyrite, chalcopyrite, oxidized copper minerals, almagra, and uraninite in a gangue of fluorapatite, hydroxylapatite, magnesiohornblende, riebeckite, tremolite, actinolite, epidote and quartz. Around the veins there exist centimeters-wide alteration zones containing potassium feldspars (albite, calcite), tourmaline, actinolite, and quartz as well as chlorite-vermiculite, montmorillonite – chlorite, biotite, muscovite, goethite, maghemite, and hematite. Cobalt content measures slightly more than 0.1% (1 sample) in the most oxidized zones of these deposits and within the presence of limonite, jarosite, and oxidized copper minerals; while Co-content in the hypogene zone is less than 0.01% (5 samples) (Díaz et al., 2010).

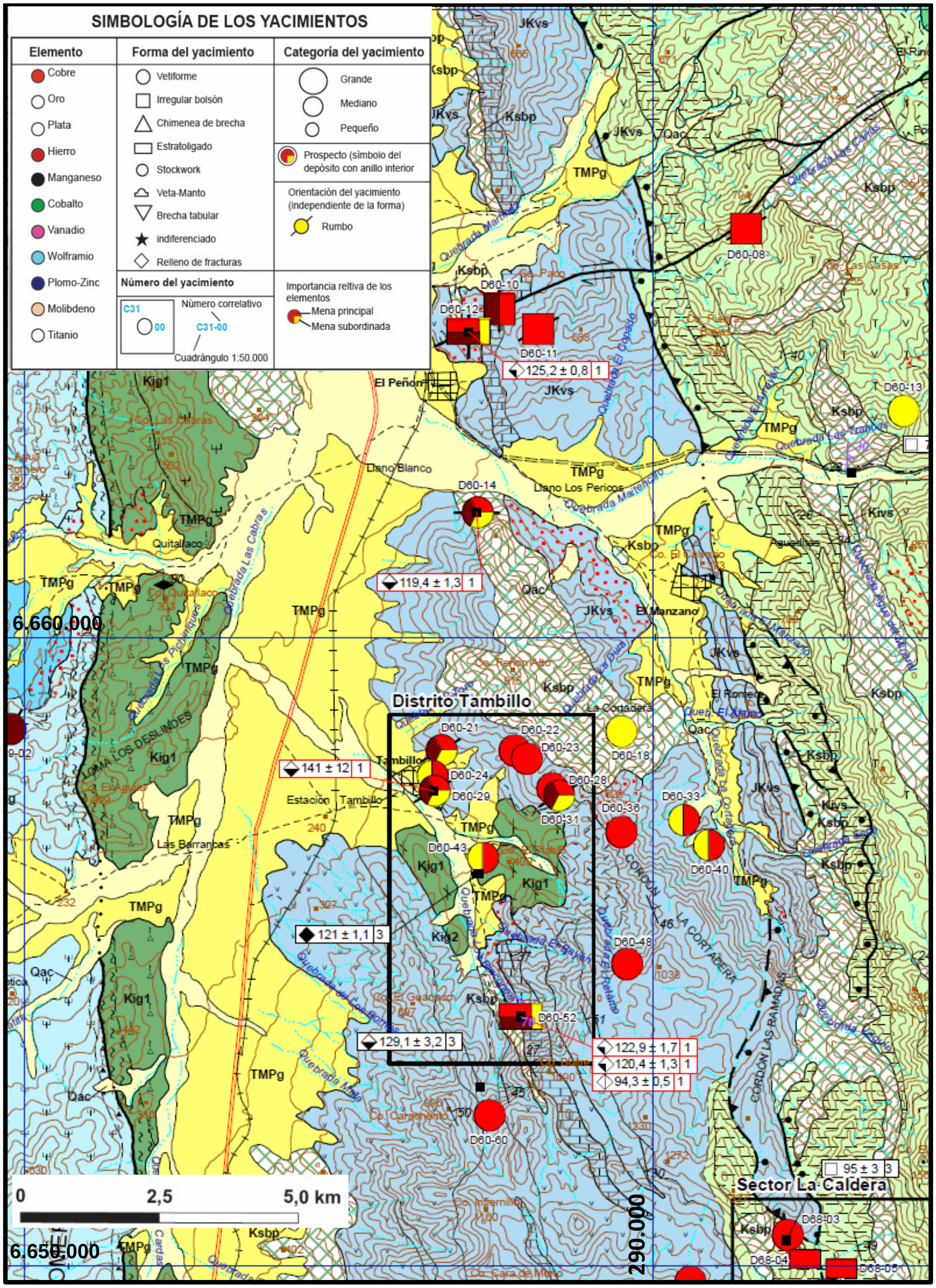


Figure 4.13. Geological context of the Tambillos District (taken from Díaz et al., 2010: to see the map in more detail, the reader should refer to the original map).

Mining Resources

There is no current information about the resources and ore grades for the Buitre and Minillas mines. It is assumed that the scarce waste rock deposits should contain Co grades valuing less than 1%. Although they have not been measured, the existing volume of tailings in the district, the result of processing the strata-bound Tambillos deposits by Cia. Minera Florida, should contain concentrations of cobalt. Vein bodies in the zone north of the Tambillo district are current objects of exploration, the objective of which is to estimate the mineral resources and to determine their cobalt content. Upon visiting the location, tunnel excavations cutting vein lines were found in the Farellón mine, and a drilling campaign was underway (Andrés Encina, Comet Exploration; verbal communication).

4.1.2.2. On site revision and sample collection

The Tambillo district is hosted mainly within a volcanic and sedimentary stratified sequence of the Upper Jurassic – Lower Cretaceous (Arqueros Formation, Ka). The sequence of the volcanic rocks are mainly andesitic-basaltic, varying from dark gray to dark brown, with marine sedimentary intercalations in between, mostly limestones, sandstones and shales, in ochre, orange and greenish brown colors; of thick stratification (each sedimentary stratum 2-40 m thick) and partly of solid aspect (Fig. 4.14).

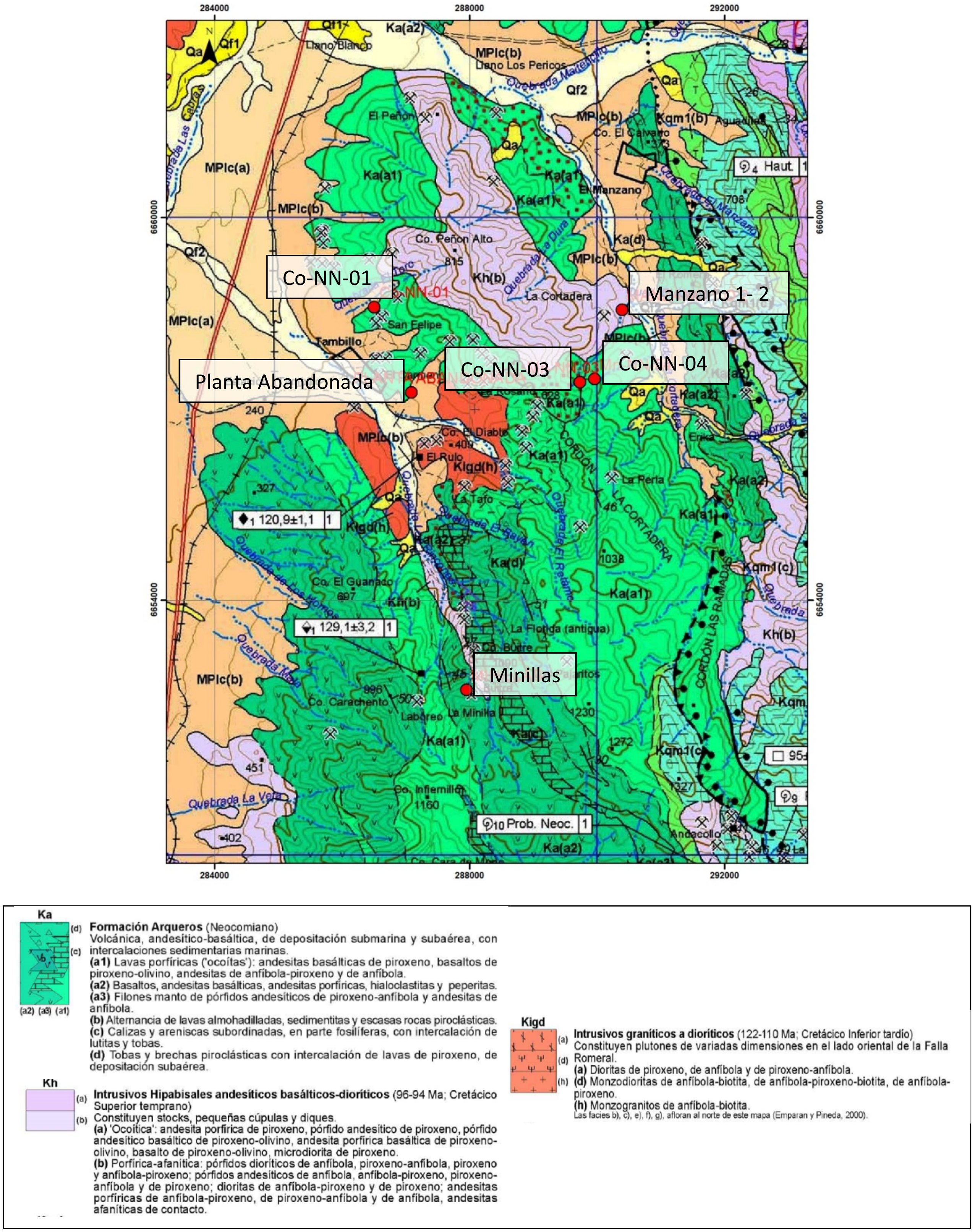
South of Tambillos features the following facies: Facies a1, made up mainly of porphyry lavas, with large plagioclase and mafic mineral phenocrystals. It includes piroxene andesitic-basalts, piroxene-olivine basalts, and amphibole-piroxene and amphibole andesites (Fig. 4.14).

The Arqueros Formation is intruded by Granitic to Dioritic Intrusives (Late Lower Cretaceous), comprised by plutons of different dimensions on the oriental side of the Romeral Fault, mainly amphybole-biotite Monzogranites (Kigd (h)). In the north and south part of the Tambillos district the volcanic rocks of the Arqueros Formation are intruded by hypabyssal andesitic basaltic-dioritic intrusives (early upper Cretaceous), that include: amphibole, piroxene-amphibole, piroxene and amphibole-piroxene dioritic porphyries; amphibole, amphibole-piroxene, piroxene-amphibole and piroxene andesitic porphyries; amphibole-piroxene and piroxene diorites; amphibole-piroxene, piroxene-amphibole and amphibole porphyritic andesites, and contact aphanitic andesites (Kh (b)) (Fig. 4.14).

Sample gathering at the Tambillos district

Eight samples from different mines and one from the tailings of an abandoned plant were collected at the Tambillos district, which are listed in Table 4.5, and their location shown in Figure 4.14.

Following Table 4.5 a brief description of the sites and of the samples obtained is provided.



Formación Arqueros (Neocomiano)
Volcánica, andesítico-basáltica, de depositación submarina y subaérea, con intercalaciones sedimentarias marinas.
(a1) Lavas porfíricas ('ocoítas'): andesitas basálticas de piroxeno, basaltos de piroxeno-olivino, andesitas de anfíbola-piroxeno y de anfíbola.
(a2) Basaltos, andesitas basálticas, andesitas porfíricas, hialoclastitas y peperitas.
(a3) Filones manto de pórfidos andesíticos de piroxeno-anfíbola y andesitas de anfíbola.
(b) Alternancia de lavas almohadilladas, sedimentitas y escasas rocas piroclásticas.
(c) Calizas y areniscas subordinadas, en parte fosilíferas, con intercalación de lutitas y tobas.
(d) Tobas y brechas piroclásticas con intercalación de lavas de piroxeno, de depositación subaérea.

Intrusivos Hipabisales andesíticos basálticos-dioríticos (96-94 Ma; Cretácico Superior temprano)
Constituyen stocks, pequeñas cúpulas y diques.
(a) 'Ocoítica': andesita porfírica de piroxeno, pórfido andesítico de piroxeno, pórfido andesítico basáltico de piroxeno-olivino, andesita porfírica basáltica de piroxeno-olivino, basalto de piroxeno-olivino, microdiorita de piroxeno.
(b) Porfírica-afanítica: pórfidos dioríticos de anfíbola, piroxeno-anfíbola, piroxeno y anfíbola-piroxeno; pórfidos andesíticos de anfíbola, anfíbola-piroxeno, piroxeno-anfíbola y de piroxeno; dioritas de anfíbola-piroxeno y de piroxeno; andesitas porfíricas de anfíbola-piroxeno, de piroxeno-anfíbola y de anfíbola, andesitas afaníticas de contacto.

Intrusivos graníticos a dioríticos (122-110 Ma; Cretácico Inferior tardío)
Constituyen plutones de variadas dimensiones en el lado oriental de la Falla Romeral.
(a) Dioritas de piroxeno, de anfíbola y de piroxeno-anfíbola.
(d) Monzodioritas de anfíbola-biotita, de anfíbola-piroxeno-biotita, de anfíbola-piroxeno.
(h) Monzogranitos de anfíbola-biotita.
Las facies b), c), e), f), g), afloran al norte de este mapa (Emparan y Pineda, 2000).

Figure 4.14: Modified geological map of the Andacollo-Puerto Aldea Geology, Region of Coquimbo 1:100.000 (Emperan and Pineda, 2006). The location of the samples obtained is marked with red dots.

Table 4.5: Overview of the samples gathered at the Tambillos Mining District. The yellow color highlights the sample obtained at the abandoned plant.

CORRELATIVO	UTMN PSAD 56	UTME PSAD 56	UTMN WGS 84	UTME WGS 84	CODIGO MUESTRA	DISTRITO	MINA
27	6652596	287951	6652264	287750	Mi1	TAMBILLO	MINILLAS
28	6652596	287951	6652264	287750	Mi2	TAMBILLO	MINILLAS
29	6652596	287951	6652264	287750	Mi3	TAMBILLO	MINILLAS
30	6657255	287090	6656926	286891	REL1	TAMBILLO	PLANTA ABANDONADA
31	6658600	286505	6658269	286304	TB-01	TAMBILLO	Co-NN-01
32	6658551	290387	6658218	290187	MN-01	TAMBILLO	MANZANO 1 Ó 2
33	6657417	289724	6657085	289526	MN-02	TAMBILLO	Mn-NN-03
34	6657417	289724	6657085	289526	MN-03	TAMBILLO	Mn-NN-03
35	6657470	289952	6657140	289751	MN-04	TAMBILLO	Mn-NN-04

Co-NN-01, Mn-NN-03 y Mn-NN-04: mines with no name and no information

Abandoned Plant: located at the El Carmen locality (Fig. 4.14 and Table 4.5). This site gave access to an abandoned tailings plant, from which a tailings sample with abundant magnetite (Fig. 4.15) was obtained.

Figure 4.15: Abandoned plant tailings deposit in the proximity of the El Carmen locality, Tambillos district.

Minillas Mine: Located south, at the Quebrada Los Rincones creek. At this site rocks of the Arqueros Formation outcrop, intruded by andesitic hypabyssal basaltic-dioritic porphyries previously described (Fig. 4.14 and Table 4.5). The sampling was obtained from mine stripping piles containing: volcanic and volcanosedimentary amphibole altered rocks, with pyrite-(chalcopyrite-arsenopyrite) mineralization, veins with calcite-pyrite-(chalcopyrite-molibdenite) and volcanoclastic rocks with cobaltite-erythrite. A total of three samples were collected (Fig. 4.16).

Figure 4.16: Upper open pit at the Minillas mine (inaccessible by vehicle).

Co-NN-01 Mine: located north of Tambillo and south of Quebrada El Toro creek. At this site, rocks of the Arqueros Formation outcrop, intruded by hypabyssal andesitic-basaltic-dioritic porphyries, these previously described (Fig. 4.14 and Table 4.5). Sampling was done from mine stripping rock piles with magnetite-(calcite)-chalcopyrite-pyrite-amphibole-epidote-erythrite. One sample was collected at this location.

Manzano 1 or 2 Mine: Located on the northeast part of the Tambillo District, in the area of La Cortadera, where the two ravines La Cortadera and El Alamo converge. At this site, rocks of the hypabyssal andesitic-basaltic-dioritic porphyries outcrop, these previously described. Sampling was obtained from mine stripping piles of veins with magnetite-(calcite)-chalcopyrite-amphibole-apatite-epidote. One sample was collected.

Mn-NN-03 Mine: located northeast of the Tambillo district, in the La Cortadera area, west of Quebrada La Cortadera creek. In this area rocks of the Arqueros Formation outcrop, intruded by the hypabyssal andesitic-basaltic-dioritic porphyries previously described (Fig. 4.14 and Table 4.5). Sampling was obtained from mne stripping piles of meta-andesites with veins presenting magnetite-(calcite)-chalcopyrite-pyrite-amphibole-apatite-epidote, and in meta-andesite rocks with disseminations of magnetite-(calcite)-chalcopyrite-pyrite-amphibole-apatite-epidote. A total of two samples were collected.

Mn-NN-04 Mine: located northeast of the Tambillo district, in the area of La Cortadera, west side of the Quebrada La Cortadera creek. In this area, rocks of the Arqueros Formation outcrop, these intruded by hypabyssal andesitic-basaltic-dioritic porphyries previously described (Fig. 14.4 and Table 4.5). Sampling was carried out from mine stripping piles of veins with magnetite-(calcite)-

chalcopyrite-pyrite-amphibole-apatite-epidote hosted by intrusive and meta-andesite rocks. One sample was collected at this site (Fig. 4.17).

Figure 4.17: Magnetite-(calcite)-apatite-actinolite-epidote-arsenopyrite-chalcopyrite vein.

4.1.2.3. Prospective geochemical results of the Tambillos Districts

The samples collected at the Tambillos District that were obtained from mine stripping rock piles from the mine workings and veins were analyzed by means of Aqua Regia Digestion and ICP-OES analysis (AQ370, BUREAU VERITAS MINERALS LABORATORIES) for a total of 24 elements (Table 4.6).

The geochemical analysis results indicate that the samples from the Minillas Mine show values of Co of over 0.45% and two samples (Mi2 and Mi3) with values that exceeded the detection limit, that is, concentrations of more than 1% Co. The concentration of Cu informed for these samples were between 0.7% and 0.9% (Table 4.6). Important to mention is that the chemical analyses of the samples Mi2 and Mi3 report As concentrations of 1.76% and 9.31% and S values of 1.51% and 4.63%, respectively. This may be related to the occurrence of sulfide minerals, chalcopyrite, pyrite, arsenopyrite together with minerals such as cobaltite and in erythrite oxidation zones, as described in sample Mi3 (Table 4.6).

The chemical analysis of samples TB-01, MN-01, MN-02, MN-03 y MN-04, report concentrations of iron higher than 10%, emphasizing samples MN-01 and MN-04 with a concentration higher than 40% (exceeding upper detection limit, Table 4.6). In these samples the concentrations of Co are low, less than 0.03%, of copper, higher than 2% with the exception of sample MN-03, with a concentration of 0.086% Cu. Important to mention is that sample MN-02 reports a concentration a bit higher than 5.4% Cu. The concentrations of As reported are lower than the detection limit, with the exception of sample TB-01, with a concentration of 0.04%. Concentrations of S are over 1.5% reaching up to 4.18% in sample MN-02 (Table 4.6).

Table 4.6: Analytical results for Co, Cu, Mn, Fe, As and S of the samples obtained from the Tambillo District. Other elements reported in Annex 2.Name of Mine shaft and pit worksites as well as summarized description of the samples.

Muestra	Co %	Cu %	Mn %	Fe %	As %	S %	MINA	DESCRIPCIÓN - MUESTRA
Mi1	0,483	0,713	0,3	5,92	0,64	0,93	MINILLAS	Rocas volcánicas y volcanosedimentarias anfibolitizadas con Py-(Cpy-Arspy)
Mi2	>1,000	0,801	0,6	2,44	1,76	1,51	MINILLAS	Vetas Cal-Py-(Cpy-Mo)
Mi3	>1,000	0,817	0,17	4,27	9,31	4,63	MINILLAS	Rocas volcanoclásticas con Cob-Eri
TB-01	0,027	2,146	0,07	22,14	0,04	2,13	S.I.	Desmonte con vetas de Mgt-(Cal)-Cpy-Py-Anf-Epdt-Eri
MN-01	0,005	1,887	0,06	>40,00	<0,01	1,79	MANZANO 1 Ó 2	Vetas de Mgt-(Cal)-Cpy-Py-Anf-Ap-Epdt en intrusivo
MN-02	0,002	5,485	0,13	10,23	<0,01	4,18	S.I.	Vetas de Mgt-(Cal)-Cpy-Py-Anf-Ap-Epdt en metandesita
MN-03	0,003	0,086	0,12	10,57	<0,01	0,07	S.I.	diseminado de Mgt-(Cal)-Cpy-Py-Anf-Ap-Epdt en metandesita
MN-04	0,028	2,255	0,07	>40,00	<0,01	3,12	S.I.	Vetas de Mgt-(Cal)-Cpy-Py-Anf-Ap-Epdt en intrusivo y metandesita

S.I.: No information; Qzo: Quartz; Cal: Calcite; Mgt: Magnetite; Cpy: Chalcopyrite; Arspy: Arsenopyrite; Py: Pyrite; Mo: Molybdenite; Anf: Amphibole; Epdt: Epidote; Ap: Apatite; Eri: Erythrite

The deposits exploited for cobalt are of the stratified type, specifically the Buitre and Minillas mines. These mineralized mantos strike N15-35°W and dip between 45 and 55°W. The manto consists of an actinolite hornfel rock with fewer amounts of recrystallized calcite, together with abundant interstitial chlorite. The hanging wall corresponds to meta-andesites that in general present a potassic alteration defined by the presence of biotite and potasic feldspar, while the pending wall is comprised of continuous chert layers. The primary ore mineralogy presents chalcopyrite, pyrite, arsenopyrite, sphalerite, galena, cobaltite and tetrahedrite, as well as small amounts of erythrite at the superficial oxidation zones. Cobaltite is mainly present at the contact zone between the mineralized manto and the chert and in less degree as coarse disseminations within the manto, together with the other mentioned sulfides.

Table 4.7 indicates the geochemical analysis results of a tailings sample from an abandoned plant (sample REL1). Concentration of Co is 0.018%, Cu 0.129%, and most noteworthy the concentration of Fe is 15.85%, associated to abundant magnetite reported in the sample description.

Table 4.7: Analitical Results for Co, Cu, Mn, Fe, As and S, rest of the elements reported in Annex 2, all obtained from the abandoned plant. Mine shaft and pit worksite name and summarized sample description.

Muestra	Co %	Cu %	Mn %	Fe %	As %	S %	MINA	DESCRIPCIÓN - MUESTRA
REL1	0,018	0,129	0,17	15,85	<0,01	0,27	PLANTA ABANDONADA	Relave con abundante Mgt

The on-site observations, the geochemical results and the information described previously, indicate that the Tambillos District maintains a high potential for cobalt, that together with copper, iron and most probably gold, describe a prospective area of high interest due to the existing polymetallic ores. At present and for a long time the different deposits have been exploited for their content of copper, without knowledge about the recovery of other minerals. Notwithstanding the above, given the high proportions of magnetite, it would be convenient to analyze these tailings to evaluate the recovery of magnetic iron and the progressive concentration of other heavy minerals, among these, cobalt minerals.

4.1.3. Los Morteros District

The access to the Morteros District is from the city of Vallenar on road C-479 that connects this city with the town of Hornitos (Fig. 4.18).

Figure 4.18: Location and access map to the Los Morteros District. Blue rectangle indicates approximate location.

The outcropping rocks at the zone from where the samples were obtained belong to the **Bandurrias Group (Neocomian)** (Fig. 4.19) that in general correspond to andesitic volcanic rocks with clastic sedimentary and marine calcareous intercalations.

At the sampling area the lithology consists mainly of porphyric andesites with large plagioclase phenocrysts in an aphanitic mass; andesitic breccias, brecciated tuffs and brecciated sandstones, reddish in color.

Towards the east overlies the Chañarcillo Group, in erosion and angular discordance (Fig. 4.19), this unit comprised of a sequence of marine sedimentary rocks, composed mainly of fossiliferous limestones, limy sandstones and mudstone levels, these last bearing neocomian fauna.

In the area there are sediments that belong to the Gravas de Atacama that form a large hanging terrace, that discordantly rests on rocks from the Chañarcillo Group and from the Cerrillos Formation (Fig. 4.19). These sediments correspond to gravel of regular selection, with angular clasts less than 10 cm in size, with a coarse to fine sand matrix. These sediments are approximately 60 m thick.

The Bandurrias Group is intruded by extensive plutons from the **Central Belt**, constituted by elongated shaped plutons oriented NS to NNE (Fig, 4.19). The granodiorites are widely distributed along the border of this region. In the area of the Huasco River, Bembow (1980) described biotite and hornblende granodiorites of white-yellowish colors made up of sericite altered plagioclase (andesine), potassium feldspar, abundant quartz, biotite and chloritized hornblendes, and scarce pyroxene, apatite, sphene and magnetite as accessory minerals.

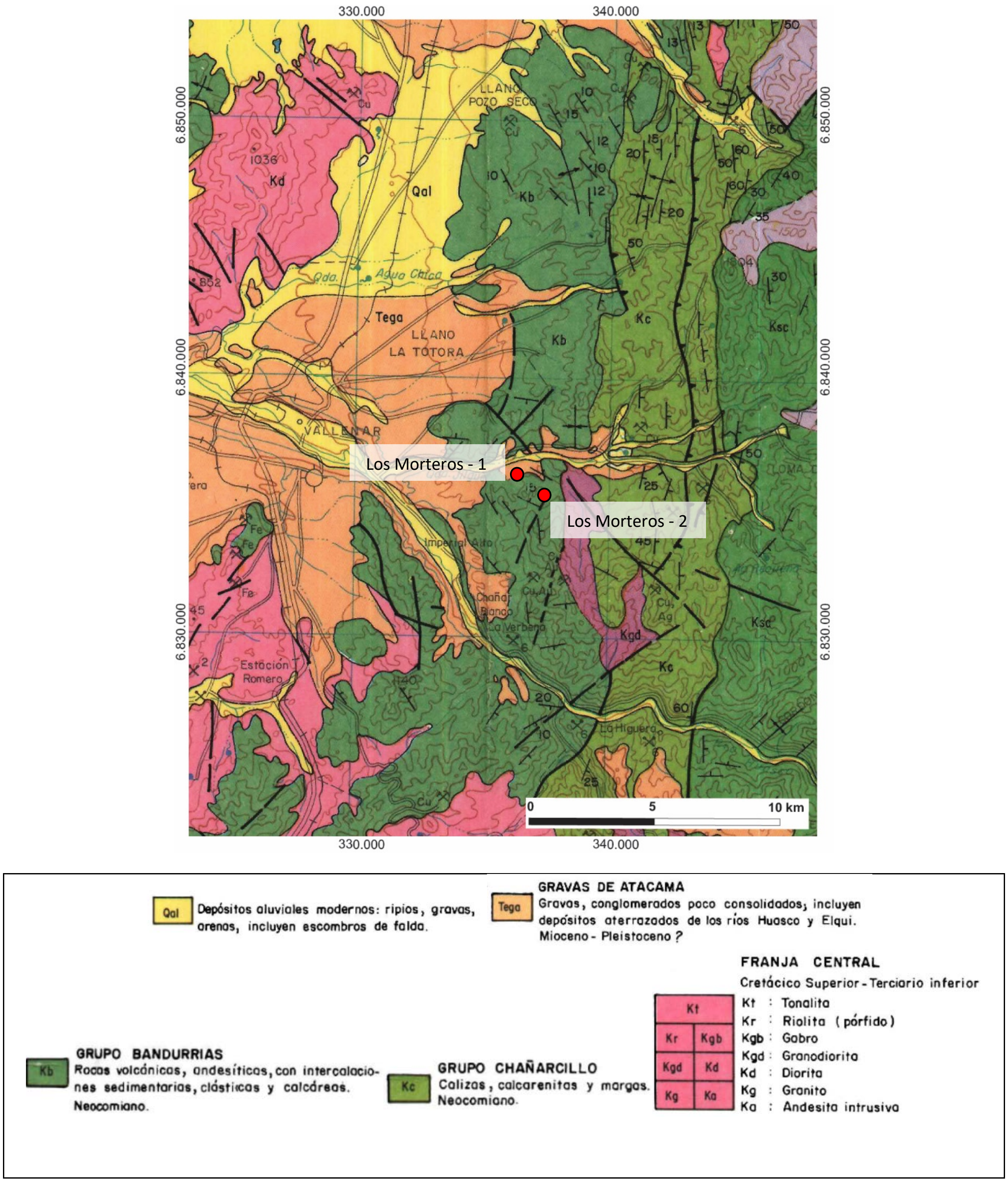


Figure 4.19: Modified geological map of Vallenar Sheet and the North part of La Serena 1:250.000 (Moscoso et al., 1982). Red dots indicate sample gathering sites.

There is very little evidence of alteration and mineralization in the district, these consistent in rock outcrops that show a pervasive replacement to magnetite, hematite, with less pyrite and scarce chalcopyrite mineralization, associated with propylitic or calc-sodic hydrothermal alteration. Minor green oxidized copper mineralization is present. There are also abandoned worksites and pit stripping, but the area shows clear signs of abandonment.

4.1.3.1. Samples obtained at the Los Morteros District

During the visit to this district two samples were taken at the locations indicated in Figure 4.19 and that are described hereunder.

Sector Los Morteros-1: A sample of the mine stripping rock pile was collected, access to the mine not possible. The rock corresponds to a porphyrytic andesite with pervasive replacement to magnetite-actinolite (chlorite) and pyrite-chalcopyrite-pyrrhotite disseminated and veinlet mineralization. Tourmaline / quartz breccias are observed.

Sector Los Morteros-2: Sample of a mine shaft stripping rock pile was collected, access to the mine shaft not possible. At the entrance of the mine shaft there is a quartz vein approximately 2 m wide and that extends some hundreds of meters along strike (Fig. 4.20). In this vein earthy hematite, specular hematite, magnetite and green oxidized Cu mineralization exists.

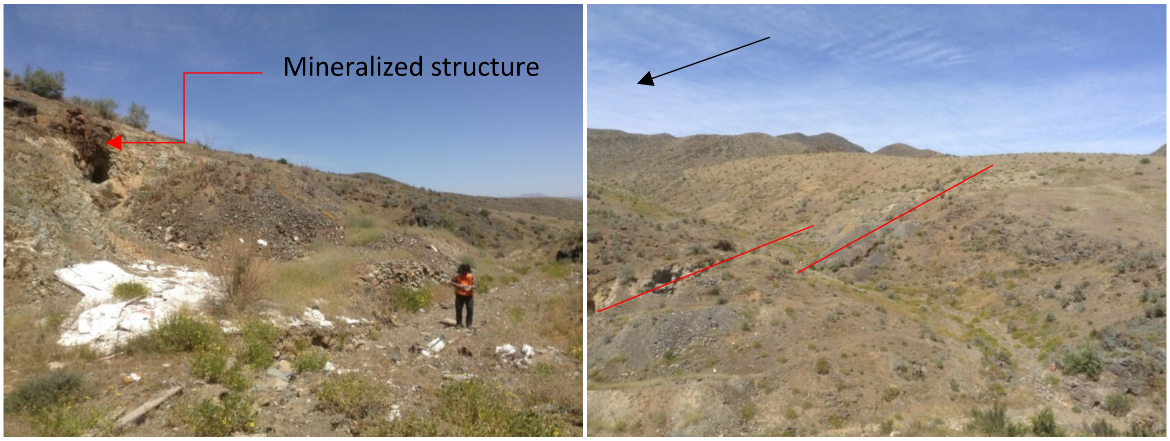


Figure 4.20: Left, photo of the mineralized structure and mine shaft. Right, photo of the vein, strike length traceability marked in red. Black arrow indicates approximate north direction.

4.1.3.2. Prospective geochemical results of the District Los Morteros

Samples collected at the Los Morteros District were obtained from the mine stripping rock piles and sent for analysis by means of an Aqua Regia Digestion and ICP-OES determination (AQ370, BUREAU VERITAS MINERALS LABORATORIES) for a total of 24 elements (Table 4.8).

Low cobalt values were reported from the samples obtained at the Los Morteros District (less than 0.002%). The values that stand out are iron with over 11% and values of Cu that exceed 0.5% (samples from the Los Morteros-02 Sector, Table 4.8).

Considering this analysis the potential for Co mineralization is low. However, worth mentioning is that the iron mineralization and the existence of minor copper mineralization hosted in sedimentary rocks could be suggestive of a potential IOGC type environment. Given that the evidence of mineralization is present in an area of abundant magnetite only, a high concentration of cobalt was not to be expected. On the other hand, there is a broad cover of present sediments that does not make it possible to evaluate the dimensions and superficial expression of alteration and mineralization in this district. Further research is recommended, not targeting an interest for cobalt, but rather for Cu-Fe and maybe Au.

Table 4.8: Analytical results for Co, Cu, Mn, Fe, As and S of the samples obtained at the Los Morteros District. The rest of the elements are shown in Annex 2. Mine shaft and pit working sites and summarized description of samples.

Muestra	Co %	Cu %	Mn %	Fe %	As %	S %	MINA	DESCRIPCIÓN - MUESTRA
Sector Los Morteros-01	0,002	0,168	0,07	11,99	<0,01	0,75	S.I.	Andesita porfídica con Mgt-Act(Clo) diseminada/pervasiva y Py-Cpy-Po, diseminada y en vetillas
Sector Los Morteros-02	<0,001	0,662	0,07	11,63	<0,01	<0,05	S.I.	Estructura (Pique) con Hmt, Mgt, Qzo, Óxidos de Cu.

Qzo: Quartz; Mgt: Magnetite; Hmt: Hematite; Cpy: Chalcopyrite; Po: Pyrrhotite; Py: Pyrite; Act: Actinolite; Clo: Chlorite.

4.1.4. El Zapallo District

The El Zapallo District is located about 27 km south of the city of Vallenar. At this district the La Estrella mine was visited, with access from Ruta 5N in direction to the south from Vallenar, and then by a secondary road to the west of this route (Fig. 4.21).

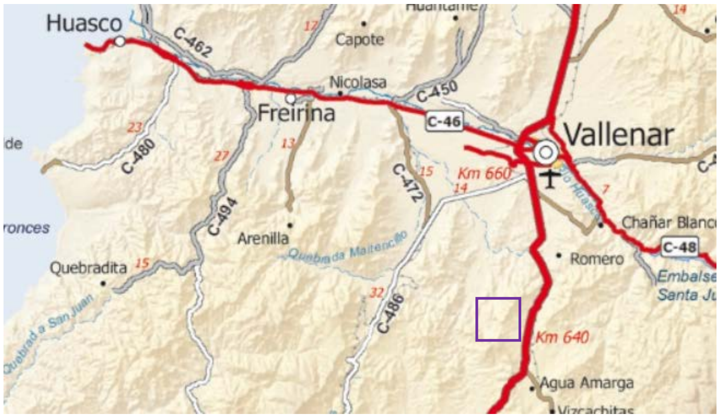


Figure 4.21. Location and road Access map to the El Zapallo District and the La Estrella mine.

4.1.4.1. Information and sample collection at the El Zapallo District

The outcropping rocks in the El Zapallo District, according to the geological map of the Vallenar Sheet and North part of La Serena (Moscoso et al., 1982), belong to the Bandurrias Group (Neocomian) (Fig. 4.21). In general the rocks from the Bandurrias Group are volcanic, andesitic in composition, with sedimentary clastic and marine calcareous intercalations. At the sampling area of the La Estrella Mine, the lithology consists essentially of porphyritic andesitic volcanic rocks with centimetric plagioclase phenocrystals in an aphanitic ground mass; andesitic breccias, brecciated tuffs and reddish brecciated sandstones.

In the surroundings of the district the rocks from the Bandurrias Group are intruded by plutons from the **Central Belt**, formed by elongated shaped intrusives oriented NS to NNE (Fig. 4.22). The predominant composition in the district is granodioritic that are widely distributed along the border. In the area of the Huasco River, Bembow (1980) described biotite and hornblende granodiorite of white-yellowish colors formed by sericite altered plagioclase (andesine), potassium feldspar, abundant quartz, biotite and chloritized hornblendes, and scarce pyroxenes, apatite, sphene and magnetite as accessory minerals.

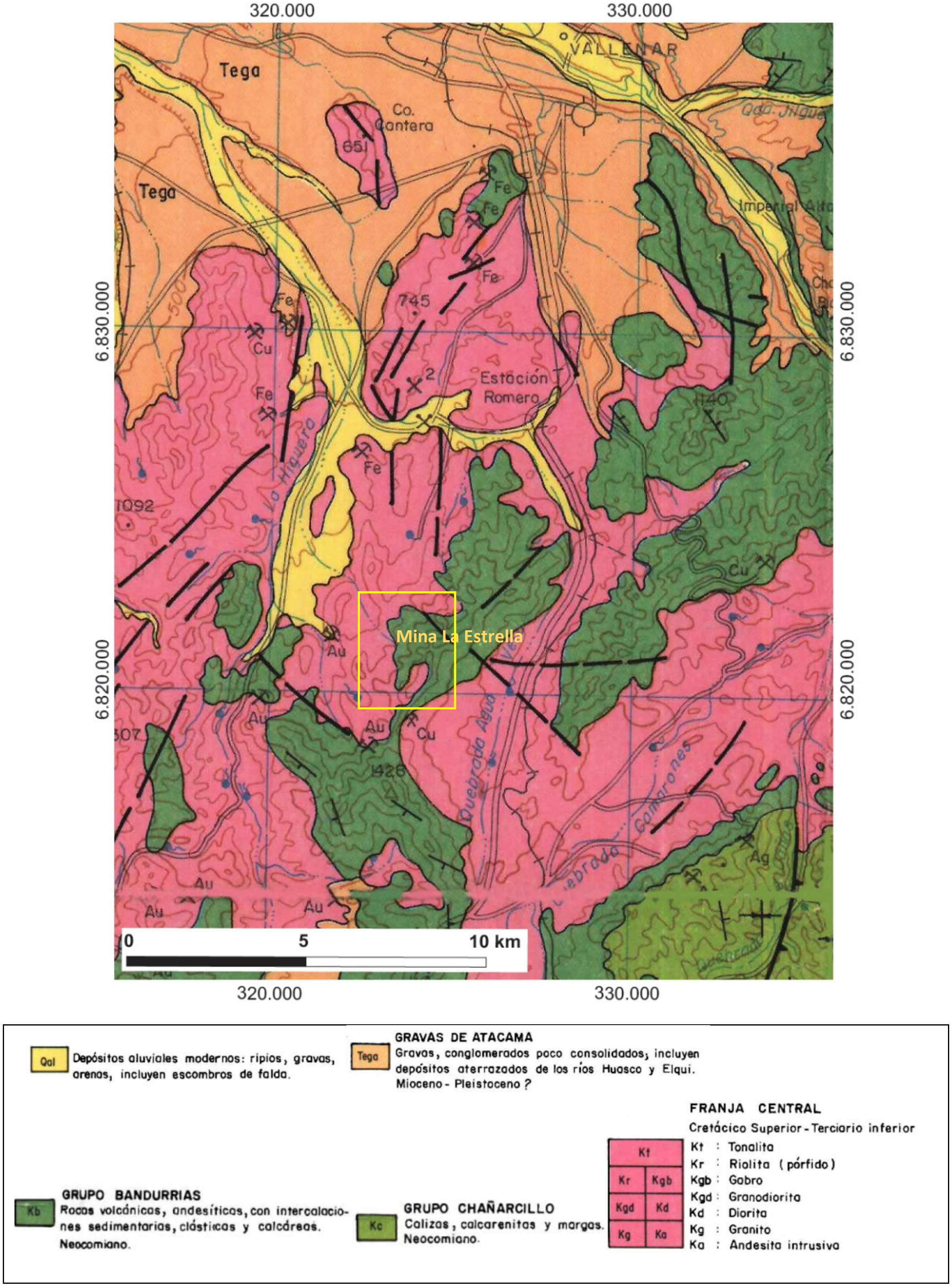


Figure 4.22: Modified geological map of Vallenar Sheet and north part of La Serena 1:250.000 (Moscoso et al., 1982). Approximate location of La Estrela Mine (sample collection site) and El Zapallo District are indicated.

It is important to mention that the La Estrella Mine and El Zapallo District are adjacent and partly within the exploration area of the Productora Project, project which belongs to the company Hot Chili Ltd. Hereunder is a summary of the information from the company webpage (www.hotchili.net.au/projects/productora/).

The Productora Project located 17 kms SSW from the city of Vallenar is 100% property of the Sociedad Minera El Águila SpA (SMEA). The Hot Chili webpage defines the Project as a porphyry copper of great potential, with an initial estimated resource of 1.5 Mt of fine copper and 1 Moz of gold, based on two resources: Breccia from the Main Zone with 218.7 Mt@0.48% Cu, 0,1 g/t Au and 142 ppm Mo and Alice with 17.9 Mt@0.41%Cu. The breccia system (129 Ma) and porphyry are emplaced in rocks of the Bandurrias Group (Fig. 4.23), rocks which are intruded to the west by the La Higuera Intrusive Complex and to the east by the Route 5 Granite (90 Ma). The alteration, mineralization and geophysics footprint in this Project presents a NNE-SSW orientation with an extension of approximately 6 km long and up to 4 km wide (Fig. 4.23). According to the geophysical and exploration information the size of La Productora could potentially be considerably larger.

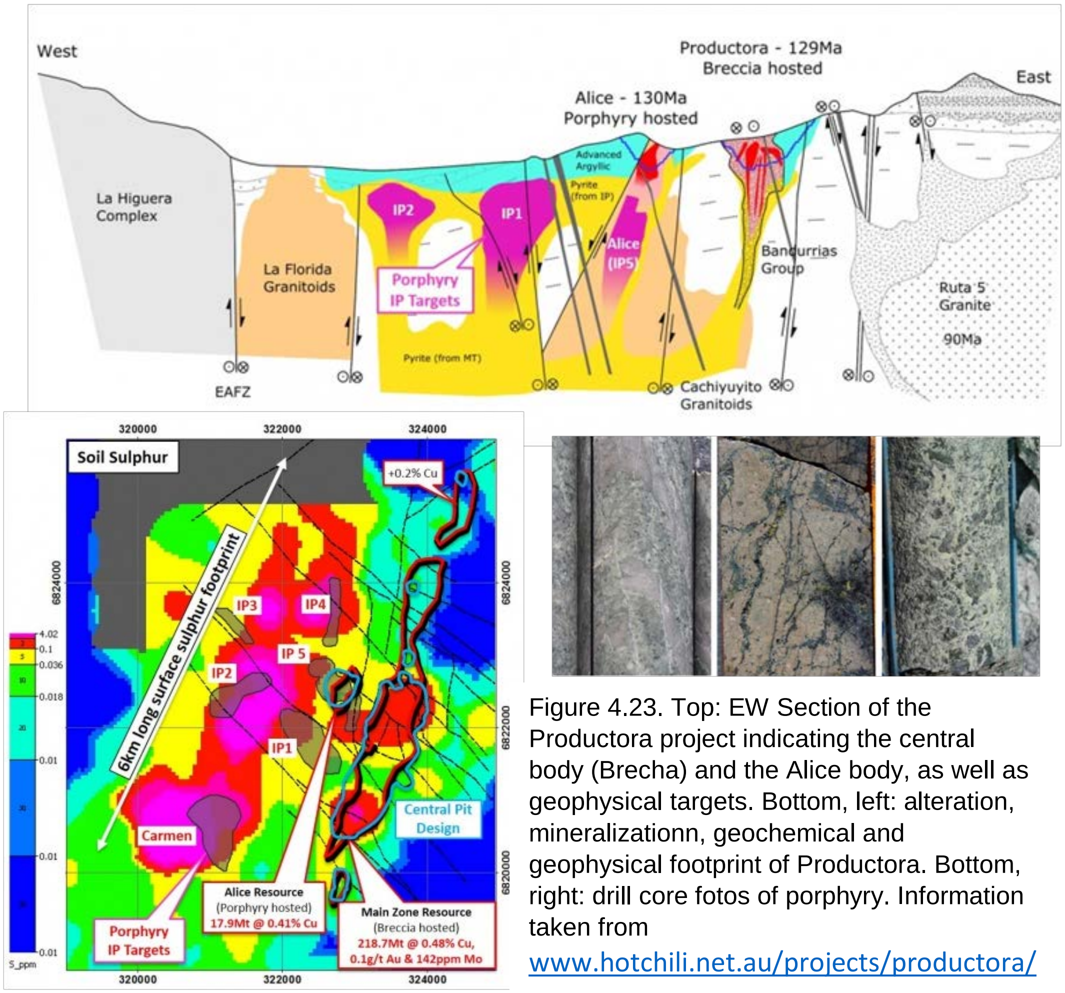


Figure 4.23. Top: EW Section of the Productora project indicating the central body (Brecha) and the Alice body, as well as geophysical targets. Bottom, left: alteration, mineralizationn, geochemical and geophysical footprint of Productora. Bottom, right: drill core fotos of porphyry. Information taken from www.hotchili.net.au/projects/productora/

Samples collected at the site (La Estrella Mine)

The samples collected at the La Estrella Mine, El Zapallo District, correspond to rock chips from extraction fronts inside the mine and from stock piles outside the La Estrella and Leona Mines (Fig. 4.24). A total of five samples were collected. Below is a description of the samples obtained.

Estrella Mine 1, 2 and 3 samples (Fig. 4.24): collected from progress and extraction fronts inside the La Estrella Mine. The lithology inside the mine corresponds to volcanic rocks from the Bandurrias Group, with a pervasive alteration and mineralization, especially biotite and chlorite alteration, with massive magnetite, chalcopyrite, pyrite, and lesser pyrrhotite mineralization. The sampled bodies at mine fronts correspond to replacement mantos in the sequence of volcanic rocks of thickness that varies from 1 to 2 m, the deepest front covering the entire advancement wall of the exploration tunnel, with a height slightly over 2 m.

Estrella 4 Mine sample: This sample was collected from the stockpile material located outside of the La Estrella Mine. It shows alteration and mineralization similar to that described in the mine.

Leona 5 Sample: collected from a mineral pile located outside the entrance shaft of the Leona Mine. It shows biotite potassic alteration and chloritization, with pyrite and chalcopyrite mineralization.

Figure 4.24. Foto of stockpile outside the La Estrella Mine (top, left) and of the samples obtained in the district. Identification of each simple is indicated in each foto.

4.1.4.2. Prospective Geochemistry of the La Estrela and Leona 5 Mines, El Zapallo District

Samples collected at the La Estrella and La Leona Mines in the El Zapallo District, were analyzed by means of an Aqua Regia Digest and ICP-OES analysis (AQ370, BUREAU VERITAS MINERALS LABORATORIES) for a total of 24 elements (Table 4.9).

The cobalt values reported from the samples collected at the La Estrella Mine are over 1500 ppm with a maximum value of 2500 ppm. The copper values exceed in average a concentration of 2%, reporting a maximum value of over 5% (Estrella 4 Mine). Important to mention is that associated to these samples the average values of iron are over 35%, exceeding in three samples the upper detection limit of 40% iron. The concentration of sulfur reported exceeds 20% on average, which corroborates, together with the high concentrations of copper and iron, the presence of sulfides such as pyrite and chalcopyrite described in the samples (Table 4.9). The concentrations of nickel reported are over 0.2% with a maximum concentration close to 1% (Estrella 1 Mine sample). The concentrations of arsenic are low, in general below the detection limit, which suggests that the existence of cobalt could be in the form of sulfide minerals.

Table 4.9: Analytical Results for Co, Cu, Mn, Fe, As and S, for samples obtained at the La Estrella Mine, in the El Zapallo District. Other elements are reported in Annex 2. Name of mine shaft and worksite pits, and summarized description of samples.

Muestra	Co %	Cu %	Mn %	Fe %	As %	S %	MINA	DESCRIPCIÓN - MUESTRA
MINA ESTRELLA 1	0,199	2,323	0,08	36,71	0,01	>30,00	Mina Estrella	Muestra interior mina. Manto de 30 - 40 cm. Con pirita, magnetita y calcopirita diseminada y en vetillas
MINA ESTRELLA 2	0,104	0,683	0,06	>40,00	<0,01	13,1	Mina Estrella	Muestra frente de extracción interior mina. Muestra zona superior de 1 m de espesor. Con mineralización de pirita principalmente, magnetita y calcopirita en menor proporción.
MINA ESTRELLA 3	0,251	1,333	0,04	>40,00	<0,01	25,01	Mina Estrella	Muestra frente de extracción interior mina. Muestra zona inferior de 1 m de espesor. Con mineralización de pirita principalmente, magnetita y calcopirita en menor proporción, pero mayor que la parte superior.
MINA ESTRELLA 4	0,141	5,241	0,04	>40,00	<0,01	24,43	Mina Estrella	Muestra de material de desmonte ubicado fuera de la Mina La Estrella, material seleccionado. Mineralización de pirita, magnetita y calcopirita.
LEONA 5	0,074	0,32	0,16	39,3	<0,01	9,04	Mina Leona	Muestra material de desmonte ubicado fuera de pique de entrada a Mina Leonas. Mineralización de magnetita, pirita y calcopirita.

The sample from the Leona Mine reports concentrations of cobalt of less than 1000 ppm and of copper less than 0.5%. The concentrations of iron are high, over 35% and of sulfur close to 10%.

4.1.5. Boquerón Chañar Deposit

The Boquerón Chañar Deposit is one of many iron deposits in the Region of Atacama, located within the Iron Belt of the Coastal Mountain Range (FFCC) (Ruiz et al., 1965 in Vivallos et al., 2008). This iron deposit is property of CORFO – Chile, and has been recognized only through drillings, entirely underlying beneath non-consolidated cover. It is located approximately 60 kms north of the city of Vallenar following Route 5 North (Fig. 4.25).

4.1.5.1. Regional Geology of the surroundings of the Boquerón Chañar Deposit

The Boquerón Chañar Deposit is located under an alluvial cover that reaches thicknesses of over 200 m, formed by blocks, gravel, rubble, fine clastic sand and sediments, underlying the gravels (Alluvial Deposits, PIHa and Alluvial and Old Colluvial deposits MPlia, Fig. 4.25; Arevalo and Welkner, 2008).

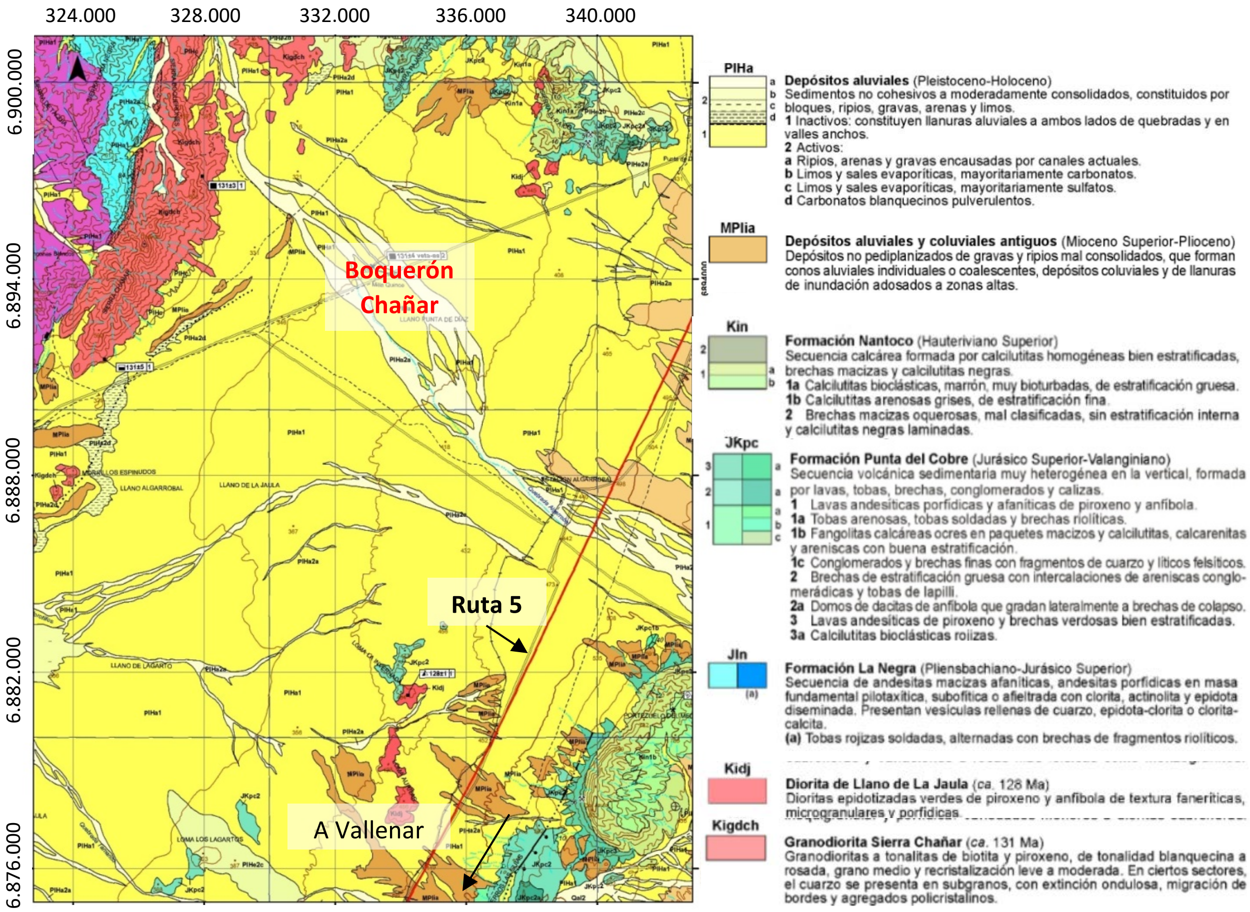


Figure 4.25: Modified geological map of the Geology Sheet from the Carrizal Bajo-Chacritas Area 1:100.000 (Arevalo and Welkner, 2008). It indicates approximate location of the Boquerón Chañar deposit (red). The samples were collected from deposit drillings. For further details of the map the reader should refer to the original Sheet from Sernageomin.

The description of the geology was extracted from the Geology Sheet of the Carrizal bajo-Chacritas Area (Arevalo and Welkner, 2008).

"The outcropping rocks to the west, where the Boquerón Chañar deposit is located belong to the Sierra Chañar Granodiorite, formed by biotite and pyroxene granodiorites to tonalites of whitish to pink color, medium grain and weakly to moderately recrystallized. In some sectors the biotite presents itself altered to chlorite, epidote, and prehnite. In others, the amphiboles show a weak to intense alteration to chlorite, actinolite, calcite, prehnite and titanite. It is in contact with volcanic rocks of the La Negra Formation, sequence of massive aphanitic andesites, andesitic porphyries, with chlorite, actinolite and disseminated epidote. It presents vesicles filled with quartz, epidote-chlorite or calcite-chlorite (Fig. 4.25).

To the north and east rocks of the Punta del Cobre Formation outcrop, a vertically very heterogeneous sedimentary volcanic sequence, formed by lavas, tuffs, conglomerates, limestones and thick stratification breccias with intercalations of conglomeradic sandstones and lapilli tuffs (Fig. 4.25). Concordantly overlying these sequences are rocks of the Nantoco Formation, that correspond to a sequence of well stratified limestones with brown bioclastic calcareous shales, highly bioturbated, of thick stratification, in banks from 1 to 2 m alternated every 5 to 10 m with well stratified calcareous sandstones and gray sandy calcareous shales of fine stratification, laid out in banks of 5 to 10 cm (Fig. 4.25).

To the southeast rocks from the Llano de La Jaula Diorite outcrop, formed by green epidote altered faneritic piroxene and amphibole diorite, microgranular and phorpyric in texture. Piroxene diorites and epidote altered green color amphiboles with faneritic, microgranular and porphyric textures. They are often intensely altered, sericite-chlorite common and occasionally presenting scapolite. The amphibole is found altered to actinolite and chloritized. Biotite presents strong oxidation. The existence of disseminated pyrites in these rocks is reported."

4.1.5.2. Sample Collection

Collection of samples for chemical analysis was performed from drill cores stored at a CMP warehouse for CORFO, located nearby the location of the Boquerón Chañar deposit, Carrizal Alto sector, close to Route 5 North. For the selection of the samples, different drill core intervals were inspected, with special interest in those reported to have a relevant occurrence of sulfide minerals, chalcopyrite and/or pyrite mainly. The sampling consisted in generating a composite of different pieces of drill core selected from 2 to 3 meter drill core intervals. A total of six samples were collected and are indicated below (reference indicates mid-point depth of composite, in feet):

- BH11-902: Drillhole 11, 902 ft
- BH12-824: Drillhole 12, 824 ft
- BH15-685: Drillhole 15, 685 ft
- BH20-489: Drillhole 20, 489 ft
- BH20-793: Drillhole 20, 793 ft
- BH21-1036,15: Drillhole 21, 1036,15 ft

The rocks are generally meta-andesites with alteration to K-feldspar and actinolite, with quartz veinlets and a mineralization of magnetite, pyrite and chalcopyrite, both disseminated and in veinlets, associated with the quartz and K-feldspar alteration (Fig. 4.26).

Figure 4.26. Photographs of drill core samples taken from the Boquerón-Chañar Mine. Left: Drillcore sample 21-1036,15. Right: drillcore sample 12-824.

4.1.5.3. Prospective Geochemistry at the Boquerón Chañar deposit

Samples of the Boquerón Chañar deposit were collected from drillcore and analyzed by means of an Aqua Regia Digestion and ICP-OES analysis (AQ370, BUREAU VERITAS MINERALS LABORATORIES) for a total of 24 elements (Table 4.10).

Cobalt values reported from the samples obtained from the drill cores of the Boquerón Chañar deposit, despite representing positive anomalies compared to the average crust, present concentrations that are lower than 0.03% and do not constitute an element of direct ore. Copper values are below 2000 ppm. Worthy of mentioning are the average iron values exceeding 30%, with one sample exceeding 40% (BH15-685), corroborating iron concentrations described in previous findings, associated mainly to the mineralization of magnetite (Table 4.10). Even though there is existence of sulfide mineralization, the low concentrations of Cu, Co and S indicate a very low potential for sulfide mineral facies. On the other hand, concentrations of arsenic below the analytical detection limit rule out the possibility of a relevant existence of cobalt sulfo-arsenides.

The analytical results, in concordance with the information of this deposit, present an exclusive iron ore opportunity, mostly magnetite. Despite this result, in case of an eventual exploitation of iron through magnetic separation, a subsequent concentration of sulfide minerals in the residual phase cannot be discarded. A metallurgic evaluation of such concentrate could open perspectives to recover credits. The latter is only possible if the exploitation and recovery of iron is made economically viable.

Table 4.10: Analytical results of Co, Cu, Mn, Fe, As and S, for the samples collected at the Boquerón Chañar Mine. Rests of elements are reported in Annex 2. Mine shaft and worksite pit names and summarized description of the samples.

Muestra	Co %	Cu %	Mn %	Fe %	As %	S %	MINA	DESCRIPCIÓN - MUESTRA
BH20-793	0,01	0,17	0,17	39,28	<0,01	0,82	Boquerón Chañar	
BH20-489	0,009	0,02	0,18	19,82	<0,01	0,42	Boquerón Chañar	
BH11-902	0,027	0,08	0,2	26,72	<0,01	2,99	Boquerón Chañar	
BH21-1036,15	0,013	0,08	0,25	17,11	<0,01	2,25	Boquerón Chañar	Sondaje BH21 BOX 80. Muestra tramos 1028,081 - 1031; 1031,0 - 1036,5; 1036,15 - 1041,46 pies. Muestras con alteración de clorita, cuarzo, actinolita, anfíbolas. Mineralización de magnetita, pirita y calcopirita diseminadas y en vetillas asociadas a cuarzo (vetillas)
BH12-824	0,012	0,05	0,16	31,96	<0,01	1,65	Boquerón Chañar	Sondaje BH12 BOX 53. Muestra tramos 820 - 824; 824 - 826 pies. Muestras con alteración de clorita, cuarzo, actinolita, anfíbolas. Mineralización de magnetita, pirita y calcopirita diseminadas y en vetillas asociadas a cuarzo (vetillas)
BH15-685	0,003	0,03	0,13	>40,00	<0,01	0,11	Boquerón Chañar	Sondaje BH15 BOX 52. Muestras con alteración de Feldespato-K, actinolita, vetillas de cuarzo. Mineralización de Magnetita, pirita y calcopirita diseminadas y en vetillas, asociadas a cuarzo y feldespato-K

4.1.6. Merceditas Mine District – El Volcán Sector – Cajón del Maipo

The Merceditas Mine is located in Cajón del Maipo, Metropolitan Region, in the area of El Volcán. Access to this mine is from the city of Santiago on route G-25 that connects the town of Puente Alto with the sector El Volcán in Cajón del Maipo on the riverside of the Volcán River (Fig. 4.27).

Figure 4.27. Location and access map to sampling sites in the Merceditas Mine sector – El Volcán sector – Cajón del Maipo. Red rectangle indicates approximate location of Mina Mercedita.

4.1.6.1. Regional Geology of the surrounding area of the Merceditas Mine-El Volcán Sector- Cajón del Maipo

In the area where the Merceditas Mine is located, continental rocks outcrop, composed of tuffs and volcanic breccias with intercalations of andesitic lavas and ryolites, and pyroclatic rocks that belong to the Abanico Formation. To the west these rocks are overlain by lavas, tuffs and ignimbrites with intercalations of breccias that belong to the Farellones Formation. The contact between formations is transitional, with wide variations from discordant to pseudo-concordant (Fig. 4.28).

Both formations are intruded by granodiorites, monzogranites and quartz monzonites from the Intrusive Unit I (Thiele, 1980).

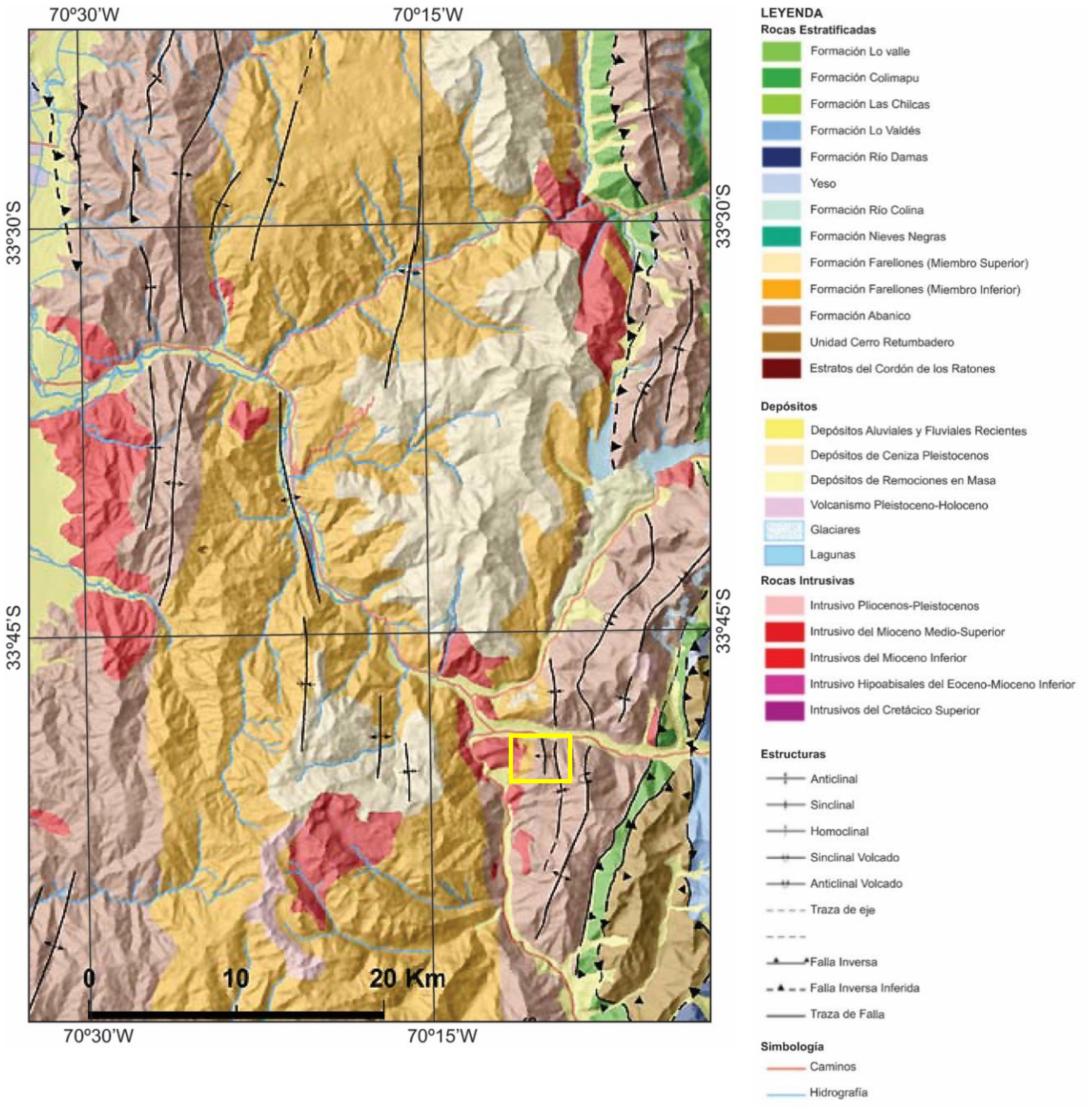


Figure 4.28. Modified geological map from Herrera (2016). Approximate location of the Merceditas Mine and District – El Volcán Sector (yellow rectangle).

4.1.6.2. Sample collection

Two samples (M-001 and M-002; Table 4.11) were collected from abandoned material in the plant area at the Mercedita Mine sector (Fig. 4.29). The existing mineralization corresponds mainly to sulfides and green copper oxidized minerals, with variable contents of pyrite, earthy and specular hematite. The rocks consist of fragments of quartz-tourmaline veins and breccias with abundant iron hydroxides (Fig. 4.29).

Figure 4.29. Abandoned works at the Merceditas mine, sample collection site (left). Extraction material samples with sulfide and green oxidized copper mineralization (right).

4.1.6.3. Prospective geochemistry of the Merceditas Mine sector – El Volcán Sector – Cajón del Maipo

Samples collected in the sector of the Merceditas Mine were analyzed by means of an Aqua Regia Digestion and ICP-OES (AQ370 analysis, BUREAU VERITAS MINERALS LABORATORIES) for a total of 24 elements (Table 4.11).

Table 4.11. Analytical results for Co, Cu, Mn, Fe, As and S, for the samples collected at the Merceditas Mine – El Volcán Sector – Cajón del Maipo, Metropolitan Region. The rest of the elements are reported in Annex 2. Mine shaft and worksite pit name and summarized description of samples.

Muestra	Co %	Cu %	Mn %	Fe %	As %	S %	MINA	DESCRIPCIÓN - MUESTRA
M-001	0,007	4,04	0,51	>40,00	<0,01	4,15	Merceditas	Zona planta, mineralización sulfuros y óxidos de cobre, Pirita, Hemtita, Hematita especular, alteración cuarzo, turmalina. Hidróxidos de Hierro.
M-002	0,17	4,308	1,19	19,78	0,21	4,22	Merceditas	Zona planta, mineralización sulfuros y óxidos de cobre, Pirita, Hemtita, Hematita especular, alteración cuarzo, turmalina. Hidróxidos de Hierro.

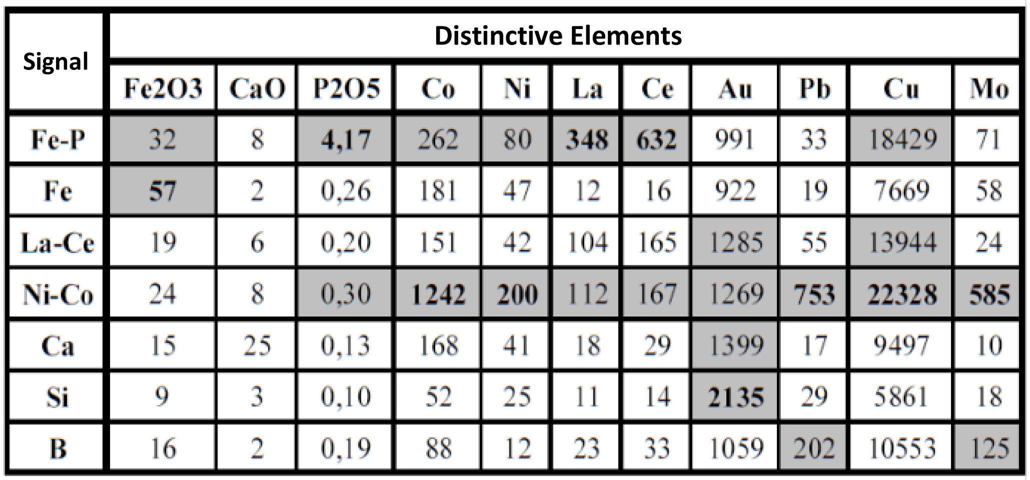
From the chemical analysis of the samples selected at the plant area of the Merceditas Mine, it is worth mentioning concentrations of over 4% copper in both samples. The concentration of cobalt reported is 0.007% (M-001) and 0.17% (M-002), iron >40% and 19.78% respectively. The reported concentrations of S and As are 4.15% and <0.01% for M-01 and 4.22% and 0.21% for M-02 (Table 4.11). This data corroborates that the presence of cobalt is associated to sulfide minerals with arsenic content, such as cobaltiferous arsenopyrites and/or cobaltite, together with magnetite, pyrite and chalcopyrite mineralization (Table 4.11).

A longtime past report (Pizarro, 1943) concludes that the Merceditas deposits are veins that cross a series of phorphyric layers (mesozoic), formed by conglomerates, breccias and tuffs. The formation of this deposit is interpreted in the mentioned report as related to a granodiorite intrusion that outcrops at the eastern foothills of the Maipo River and extends following the course of the valley. The vein filling consist of a silicified rock with ferruginous mineral impregnations (hematite and specularite) and copper sulfides with some gold and silver. There are vein zones with abundant arsenopyrite and according to petrographic studies; it replaces pyrite which in turn is replaced by chalcopyrite. Pizarro (1943) interprets that the mineralization could have originated in two mineralization episodes; the first event was the mineralization of magnetite, pyrite and cobaltiferous arsenopyrite with quartz, and the second event was the mineralization of chalcopyrite, possibly with quartz. The same study mentions that the cobaltiferous area is located preferably in the higher part of the vein, which would provide the opportunity of explorations to lower zones that have not yet been studied.

4.1.7. Other districts of interest for cobalt

In a geochemical exploration study performed by Lacassie et al. (2016) in which data processing was performed using an artificial neural network (ANN), geochemical data obtained from rock samples of ore and alteration zones were taken from different metallic mineral deposits distributed within the Metallogenic Province of the Coastal Mountain Range in the Atacama and Coquimbo regions north of the Limarí river. A total of 18 sample groups were distinguished; each one represented a deposit type with specific chemical signature and with different order peaks (Fig. 4.30). In particular, one group of deposits stood out. This group shows a first-order Ni-Co signal, corresponding to a mean value of 1,242 ppm cobalt; additionally, it has 200 ppm Ni, 2.2% Cu, and 585 ppm Mo (Table 4.12; Lacassie et al., 2016). Other signals with elevated values for Co belong to the Fe-P, Fe, Ca, and La-Ce peaks (Table 4.12, Fig. 4.30). Normally, this combination of signals is associated with IOA-type iron deposits, vein-body and irregular IOCG-type deposits, and Cu-Au vein-body mesothermal deposits, and they represent various mineralization events that have occurred from the Lower Jurassic to the Lower Cretaceous. These events occurred in different geological environments controlled by the development of successive arc and back arc systems in the Metallogenic Province of the Coastal Mountain Range, and they reflect different degrees of exposure associated with varying amounts of differential erosion.

Tabla 4.12. Average concentrations for distinctive elements and their chemical signal in metallic deposits (taken from Lacassie et al., 2016).



Signal	**Distinctive Elements**										
	Fe2O3	**CaO**	**P2O5**	**Co**	**Ni**	**La**	**Ce**	**Au**	**Pb**	**Cu**	**Mo**
Fe-P	32	8	**4,17**	262	80	**348**	**632**	991	33	18429	71
Fe	**57**	2	0,26	181	47	12	16	922	19	7669	58
La-Ce	19	6	0,20	151	42	104	165	1285	55	13944	24
Ni-Co	24	8	0,30	**1242**	**200**	112	167	1269	**753**	**22328**	**585**
Ca	15	25	0,13	168	41	18	29	1399	17	9497	10
Si	9	3	0,10	52	25	11	14	**2135**	29	5861	18
B	16	2	0,19	88	12	23	33	1059	202	10553	125

These deposits are found, in part, in the previously mentioned districts and also in the Sierra Santo Domingo (**Z1**; Fig. 4.31) and Las Ánimas (**Z2**; Fig. 4,31) districts shown on the map *Yacimientos Metalíferos de Chañaral – Diego de Almagro* (Metalliferous Deposits of Chañaral – Diego de Almagro) (Gelcich et al., 1998); in the Algorrobo – El Roble, Relincho, San Ramón – Zorroquina, and Quebrada Seca districts shown on the map *Yacimientos Metalíferos de Caldera* (Metalliferous Deposits of Caldera) (Pizarro et al., 2003) (**Z3**; Fig. 4.31); in the Punta del Cobre district shown on the map *Yacimientos Metalíferos de la Hoja Copiapó* (the Copiapo page for Metalliferous Deposits) (Díaz et al., 2006); and in the Las Pintadas district shown on the map *Yacimientos Metalíferos de la Hoja Los Loros* (the Los Loros page for Metalliferous Deposits) (Díaz et al., 1998) (**Z4**; Fig. 4.31); in the Descubridora de Quebrada Seca, Sierra El Tiuque, Totoral Norte, Quebrada Los Loros, Sierra La Noria and Sierra Algarrobilla districts shown on the map of deposits in Castilla-Totoral Bajo (Jorquera et al., 2003) (**Z5**; Fig. 4.31); and, finally, in the Carrizal Alto, Astillas, Sierra La Bandera districts and the Quebrada del Medio sector south of Freirina (Vivallo et al., 2008) (**Z6**; Fig. 4.31).

Potential cobalt mineralization outside of the regions of study: Alto Maule Valley

Finally, worth mentioning briefly is the existence of massive iron mineralization in the form of magnetite or sulfides, in two prospects located at the Alto Maule valley, Maule region (Fig. 4.32), both properties owned by Mr. Sergio Araya. The mineralization corresponds to massive mantiform replacements in Cenozoic stratified sequences of volcanic and sedimentary rocks; vein and breccia bodies that extend for more than 3 km, with variable thickness, from a few dozen centimeters up to 4 to 6 m. Even though these prospects are located outside of the priority regions considered in this present study and were not visited, a sample was obtained of the massive mantos, with pyrite mineralization, located at the Quebrada Los Baños. The analysis results (sample MAU-001) indicate low concentrations for Co and Cu, 0.02% and 0.028% respectively. However it is important to emphasize that these concentrations (200 ppm Co and 280 ppm Cu) represent positive contrast anomalies in regard to the crust. Most notable in this sample is a very high concentration of iron (31.11%), together with a very high concentration of sulfur (>30%). These results confirm massive pyrite replacement mineralization.

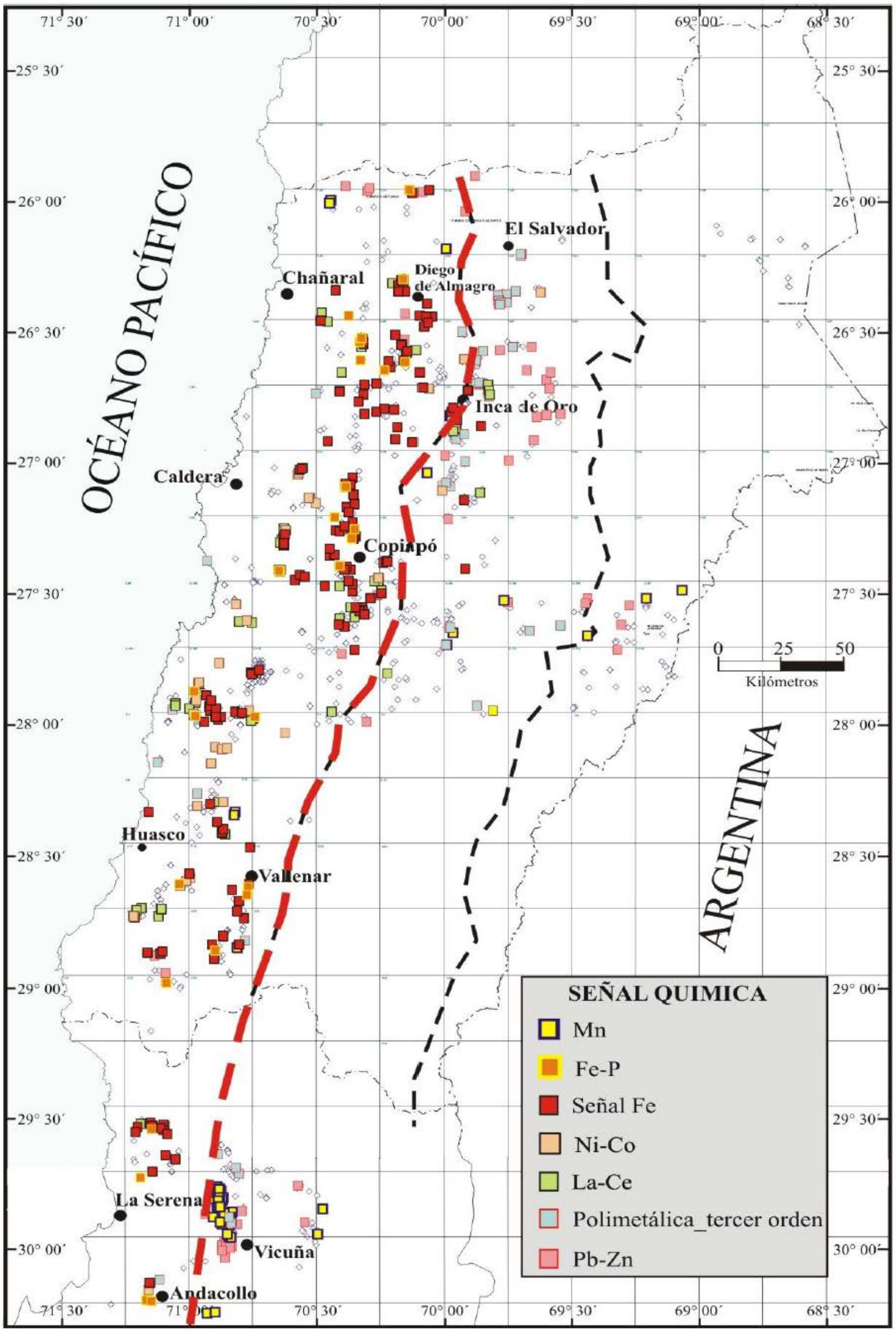


Figure 4.30. Distribution of chemical signals for metallic deposits with peaks of different orders (taken from Lacassie et al., 2016: to see in more detail, the reader should refer to the original map).

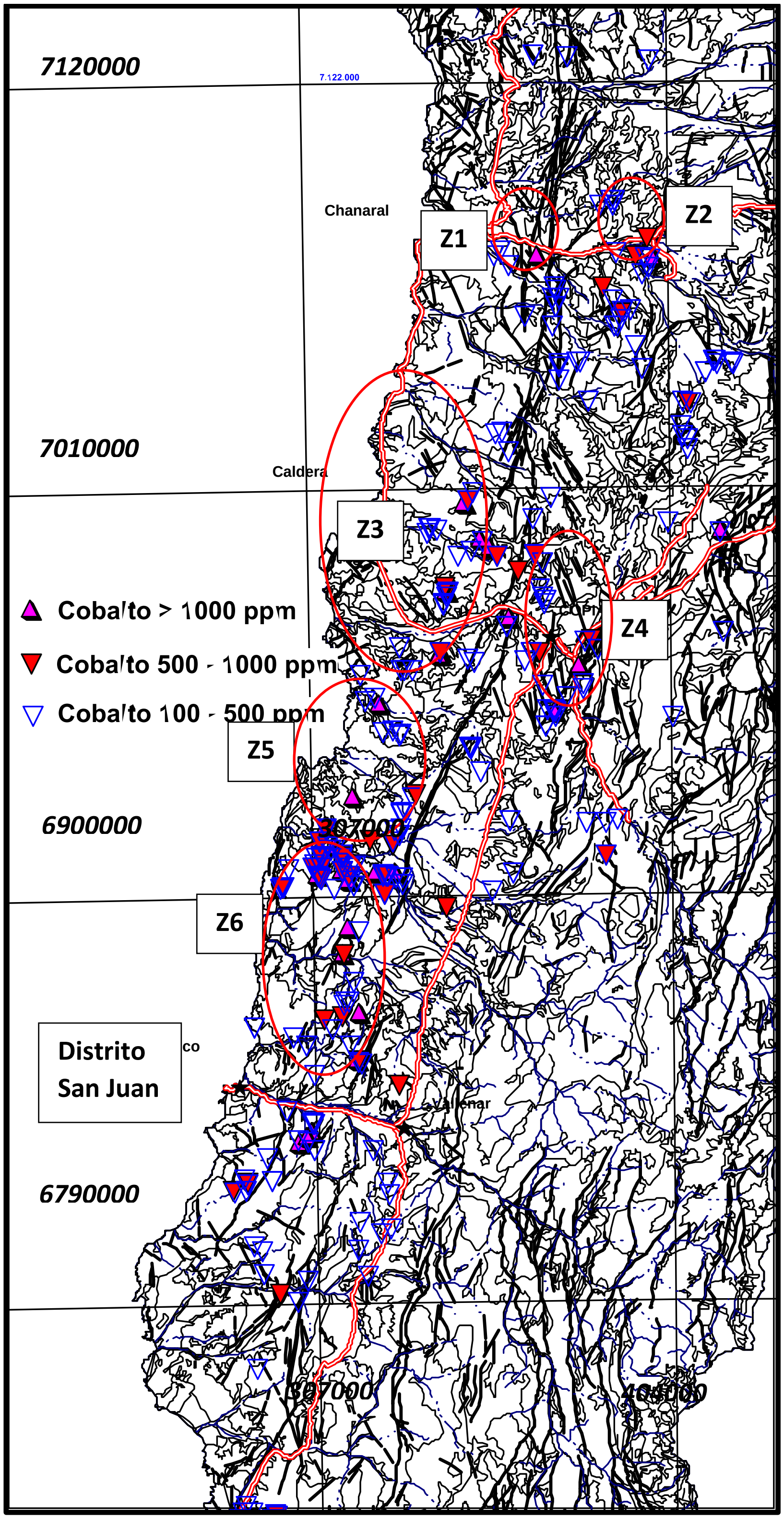


Figure 4.31. Cobalt content in deposits from other areas (Z1 to Z6) in the Metallogenic Province of the Coastal Mountain Range and their principal lineaments (to see in better detail, the reader should refer to the original map).

Information provided by a visit from third parties (Geologists Mr. Michael Corey and Mr. Patrick Burns) described the mantiform mineralization of iron as a potential iron skarn or IOCG type. The analytical results coincide closely with the results obtained in this study. Three samples from the sector Qda. Los Baños (samples 315537-39; Fig. 4.32) indicate Cu between 86 and 854 ppm, Co between 48 and 275 ppm, Fe between 26 and 30% and S between 4 and >10%. Concentrations from other elements are in general close to the crust average, without relevant contrast anomalies. During this same visit, the geologists Corey and Burns obtained a sample from the Fortuna mine (sample 315540; Fig. 4.32.). The results of this sample indicate very low concentrations of Cu and Co, 9 and 4 ppm respectively, Fe only 5.17%, Mn 2050 ppm, Pb 197 ppm and S 3.48%. The sample corresponds to a recrystallized fossiliferous limestone with fine disseminated pyrite mineralization. The analytical results of these samples are included in Annex 2.

Finally, a report submitted by the property owner (Mr. Sergio Araya) of a sample of the mineralized mantos at the Qda. Los Baños indicates concentrations for Au 0.61 ppm, Cu between 0.2 and 0.3%, Co 297 ppm, Ni 178 ppm, Fe 45% and S 40%, confirming a predominant pyrite mineralization, less magnetite and positive anomalous concentrations for Au, Cu, Co, Ni and Fe.

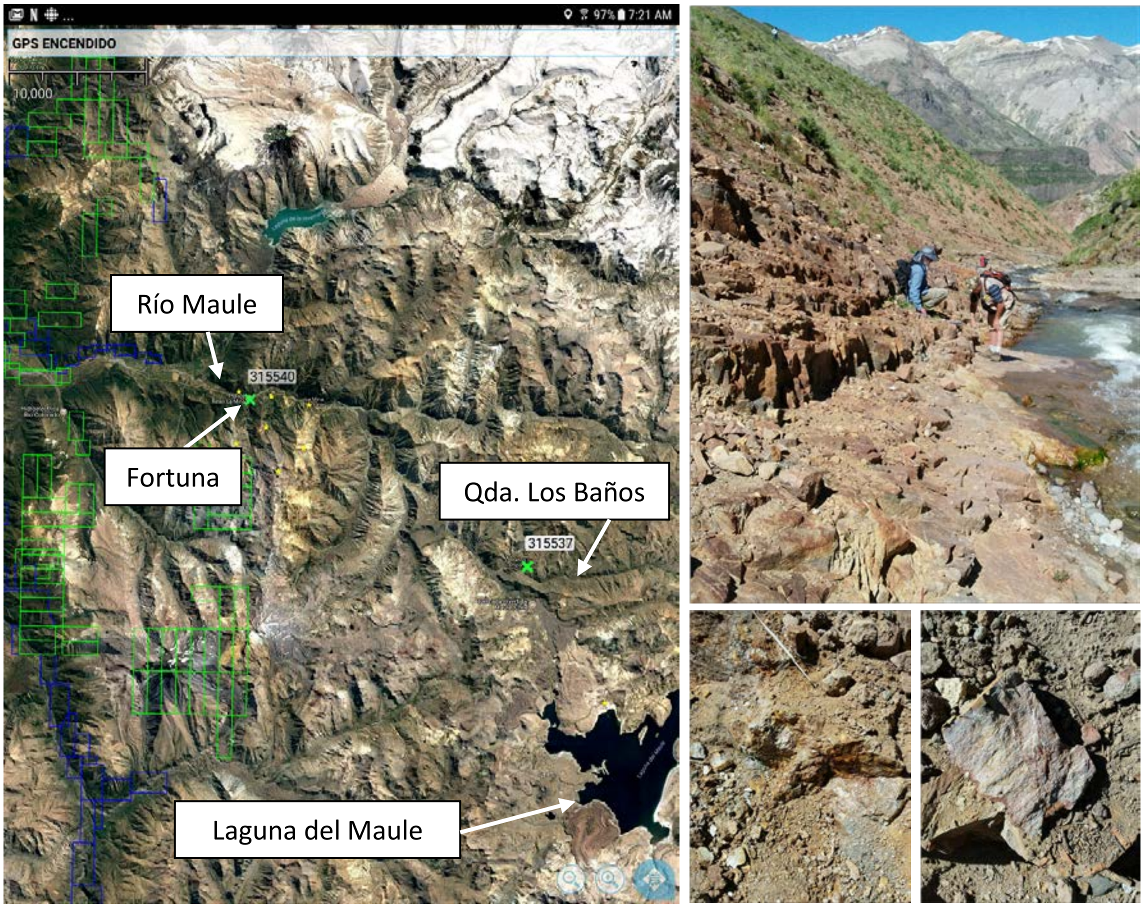


Figure 4.32. Location of massive iron oxide and sulfide mineralization in the Alto Maule valley, Los Baños River area and the Fortuna mine alongside the Maule River (left). View of the mineralized mantos and of magnetite and pyrite massive replacement mineralization (right).

4.2. Districts with manganese.

Manganese production started in Chile in the XIX century as a consequence of the international market´s demand in response to the growing use of ferromanganese in the processing of steel using the Bessemer technique. Within the first 10 years, the exploitation of deposits in Chile reached 52,000 tons annually, most exported to England. This was the peak; afterwards, production fell due to fluctuations in the price abroad, with the exception of the First and Second World War, periods at which a rise in the production of manganese in Chile occurred. Production reached record highs of 114,000 tons in 1943, only to drop dramatically at the end of the war in 1945.

According to the *Anuario de Estadísticas del Cobre y Otros Minerales 1997 – 2016* (Annual Statistics Report for Copper and Other Minerals 1997 – 2016), the production of manganese dropped from 62,887 tons in 1996 to 5,722 tons in 2009. According to registry data, the production of manganese stopped after 2009 (Table 4.13).

Table 4.13: Manganese production from the Chilean metallic mining industry (Source: Chilean Copper Commission, Annual Statistics report for Copper and other Minerals 1997 – 2016).

	1996	1997	1998	1999	2000	2001	2002	2003
MANGANESE (mT mineral)	62.887,0	63.673,0	48.931,0	40.505,0	41.716,0	31.320,0	12.195,0	19.641,0

	2004	2005	2006	2007	2008	2009	2010	2011
MANGANESE (mT mineral)	24.801,0	39.786,0	37.169,0	26.808,0	18.273,0	5.722,0	-------	------

One of the largest producers of manganese in Chile was Manganesos Atacama, a subsidiary of *Compañía Minera del Pacífico* (Pacific Mining Company). They produced 23,599 and 23,591 tons of manganese in 2004 and 2005 respectively.

Generally speaking, manganese resources in Chile are found in the Coquimbo region, the southern extent of the Atacama region, in the Altiplano of the 15th region (the Arica and Parinacota region), and in the Precambrian metamorphic sedimentary deposits in the Valdivia and Cautín provinces (Peebles and Ruiz, 1985; Ruiz and Peebles, 1988). The deposits of greatest importance have a wide distribution in the so-called Lower Cretaceous Manganese Basin of the Coquimbo region. The deposits are found in rocks from the Arqueros Formation and in rocks of the Quebrada Marquesa Formation. These have been formed in three different cycles. The oldest cycle is represented by deposits recognized in the Lambert district; the intermediate cycle is represented by the deposits in the Arqueros, Talcuna, Las Cañas (La Liga), El Arrayan, Corral Quemado, and Fragua districts; and the youngest cycle is represented by lesser deposits located in the southwest of the Talcuna district (Aguirre and Egert, 1965; Aguirre and Mehech, 1964; Aguirre, 1970). The deposits formed during the intermediate cycle are of the greatest economic interest due to their size and the continuity of the beds. In a visit to the districts in the Coquimbo region, it was apparent that the exploitation of all the manganese deposits was found paralyzed, and that the majority of them, property of CAP, were under restricted access because mine closure plans had already been executed. It was only possible to access parts of the Corral Quemado district, the Fragua district and the southern part of the Las Cañas district. All the same, the principal characteristics of the districts of interest in this area are described, and in those visited, field observations and sampling sites are described, as well as geochemical results for these.

4.2.1. Lambert District

As defined by Jorquera et al. (2011), it is found in the D3 domain shown on the map *Yacimientos Metalíferos de La Serena - La Higuera* (Metalliferous Deposits of La Serena – La Higuera) (Fig. 4.33). It is found 20 km to the northeast of the city La Serena. Its access is through the Santa Gracias valley leading up to a sector where the San Lorenzo de Lambert leaching plant is located and then continuing up the Arrayán valley. The district is characterized by the presence of vein-body and strata-bound deposits of Cu, Mn, Au and Ag.

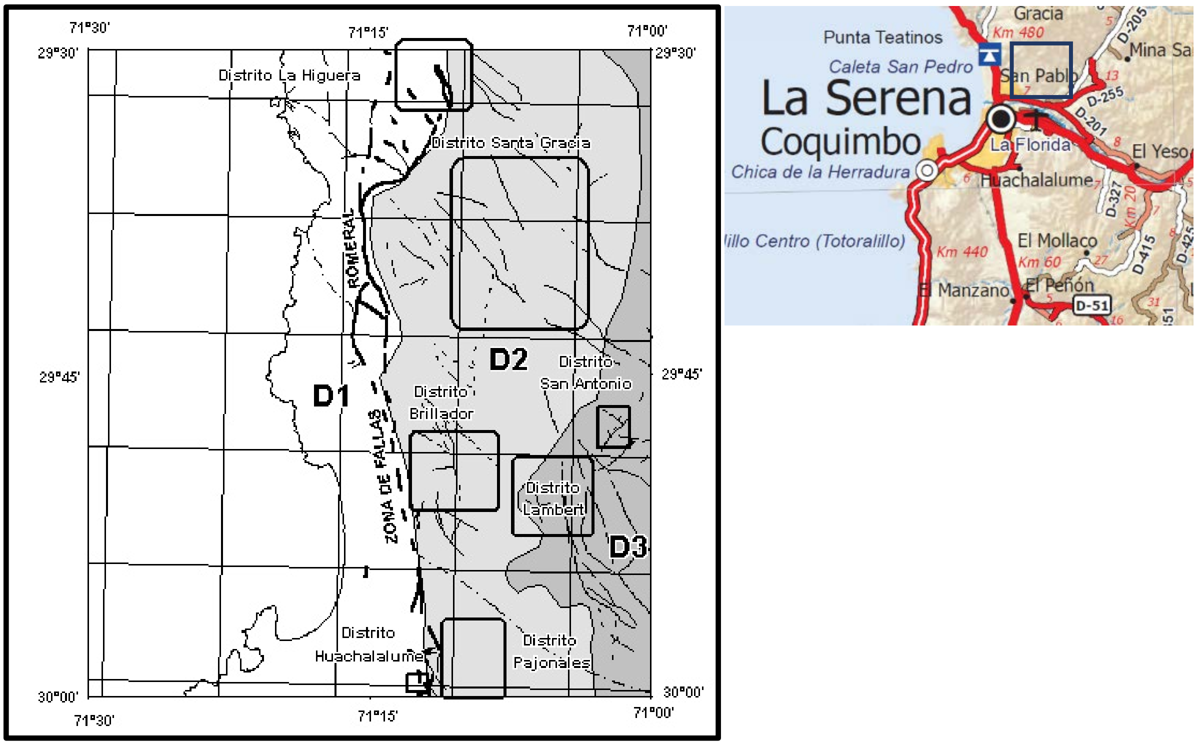


Figure 4.33. Location (upper right, black rectangle) and Metallogenic context for the principal mining districts in the La Serena – La Higuera area (taken from Jorquera et al., 2011).

In the area of this domain (Fig. 4.34), outcrops of volcanic and sedimentary rocks appear striking NNW and dipping slightly to the east, towards an area characterized by the presence of andesites, basaltic andesites, basalts, calcareous sandstones, and limestones from the Arqueros Formation (Kiv), Neocomian stage of the Lower Cretaceous. A low-angle normal fault puts these rocks in contact with epiclastic breccias and intercalated sandstones, tuffs and andesites from the Marquesa Formation (Kivs). The combination of these previously described rocks is found intruded by diorites, porphyry diorites, microdiorites, and andesites from the Lower Cretaceous (Kiq). Monzonitic to dioritic granitoids from the Upper Cretaceous (Ksg) intrude the Marquesa Formation rocks (Kivs) about 4 km to the east of the district.

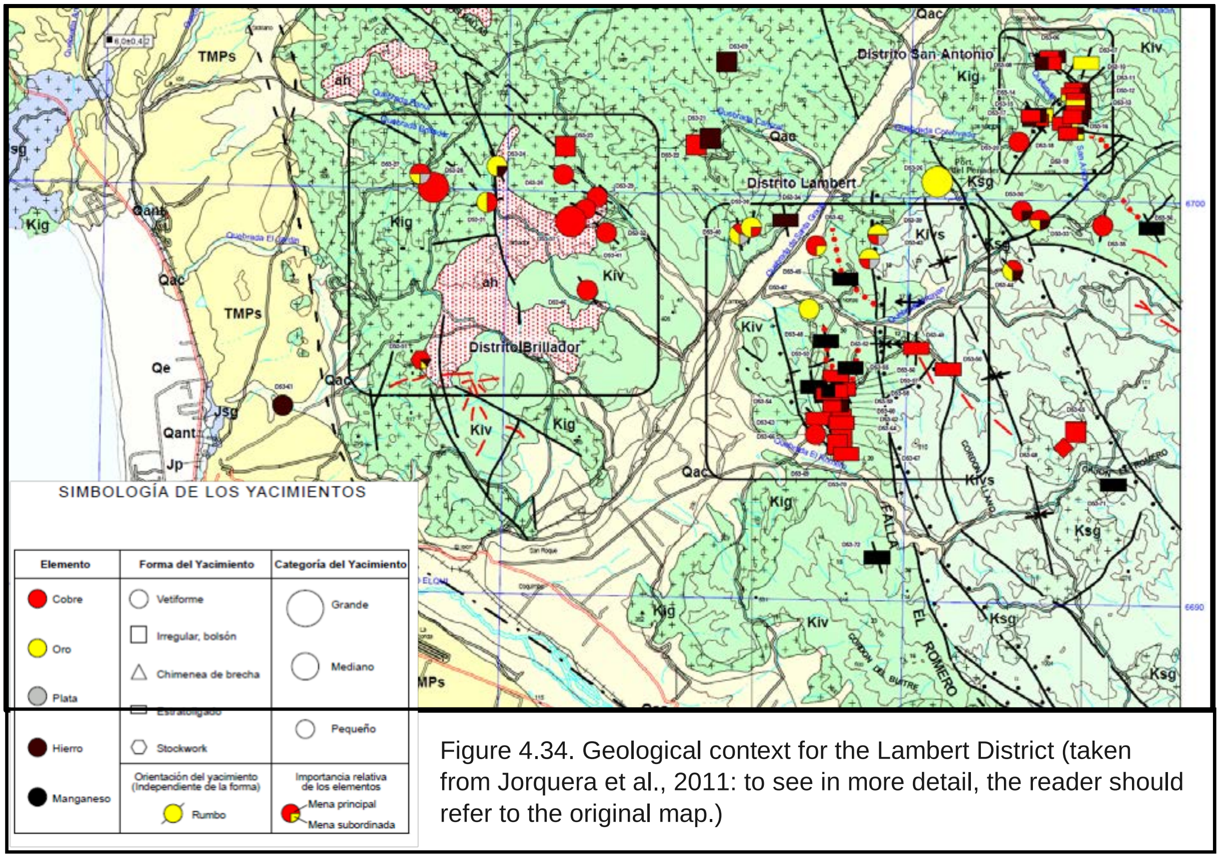


Figure 4.34. Geological context for the Lambert District (taken from Jorquera et al., 2011: to see in more detail, the reader should refer to the original map.)

Manganese deposits are strata-bound and are emplaced parallel to the containing layers, mainly tuffs, sandstones, limonites and andesites; they have a distinct NNW strike and dips varying between 10° to 30° east. These deposits extend an average of 300m with the exception of the Jamelas or Altoqui mine (D53-55 in the map of Jorquera et al., 2011), where they extend 3 km. The beds vary between 0.6 and 4m thick, averaging at 1m, and development is recognized along the dip for about 100m.

The mineralogical composition of the ore in the manganese deposits includes: pyrolusite, braunite, psilomelane and lesser quantities of oxidized Cu minerals in a calcite gangue (Jorquera et al., 2011).

4.2.2. Arqueros District.

This district is located in the D1C domain, as defined by Jorquera et al. (2012; Fig. 4.35) and described on the map *Yacimientos Metalìferos de Condoriaco – Rivadavia* (Metalliferous Deposits of Condoriaco – Rivadavia). Access to the zone involves covering a 15 km stretch north of the town of Nueva Talcuna. In this district, strata-bound deposits of Mn-Fe and Cu-Ag and vein-body Ag deposits with lesser quantities of Cu are concentrated.

The rocks that outcrop in the district (Fig. 4.36) include sandstones, volcanic breccias, epiclastic breccias, tuffs, andesites and andesite dikes from the Quebrada Marquesa Formation (Kivs) and andesites, basalts, limestones, calcareous sandstones, sandstones, conglomerates, tuffites, and lutites from the Arqueros Formation (Kiv). The combinations of rocks described here are found intruded by porphyry andesites, basalts, diorites and dacites of Upper Cretaceous age (83-76 Ma).

The expression of the Talcuna anticlinal fold, a characteristic feature that affects the stratified rocks of the Lower Cretaceous, is recognized in the southern portion of the district (Jorquera et al., 2012).

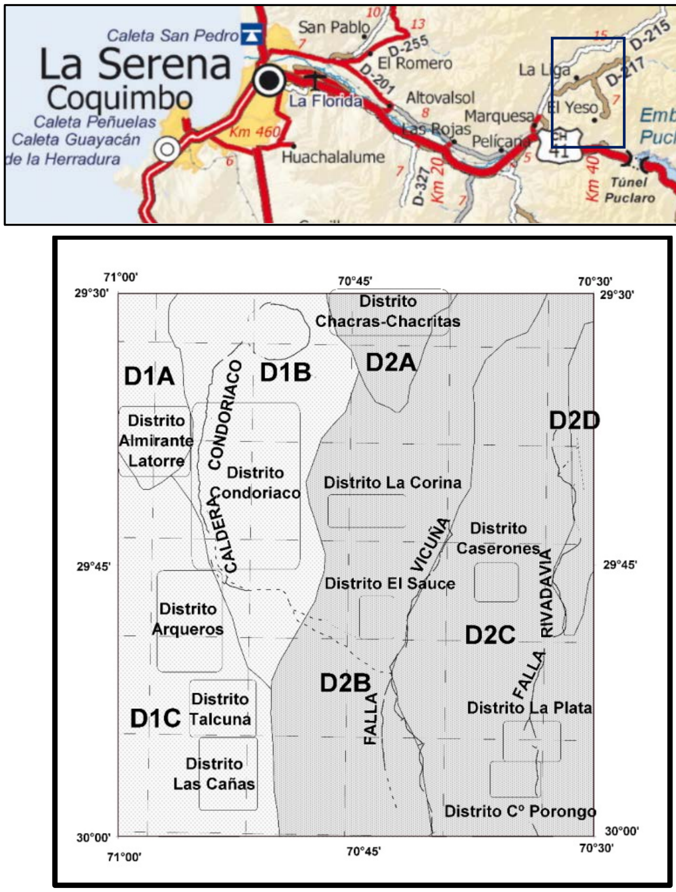


Figure 4.35. Location (top, blue rectangle), metallogenic domains and distribution of mining districts (taken from Jorquera et al., 2012).

Mn-Fe mineralization is associated with the tuffs and/or the red volcanic sandstones of the member 1(b) of the Quebrada Marquesa Formation (Kivs; Emparán and Pineda, 2000) or member 5 of the Arqueros Formation (Aguirre, 1970). The mineralized beds occur in horizons that are centimeters thick, rich in Mn and Fe minerals, intercalated with tuff and-or sandstone layers and present occasional carbonate cement. These bodies tend to be two to three meters thick and have been exploited only on a small-scale.

The results from chemical analyses done on samples from these beds indicate a chemical content of up to 20% MnO, 278 ppm to 0.61% Cu, and 946 to 25096 ppm Ba. The Pb concentrations are less than 426 ppm, except for in the La Palmira mine (D54-17) where concentrations of 4710 ppm Pb are registered (Jorquera et al., 2012).

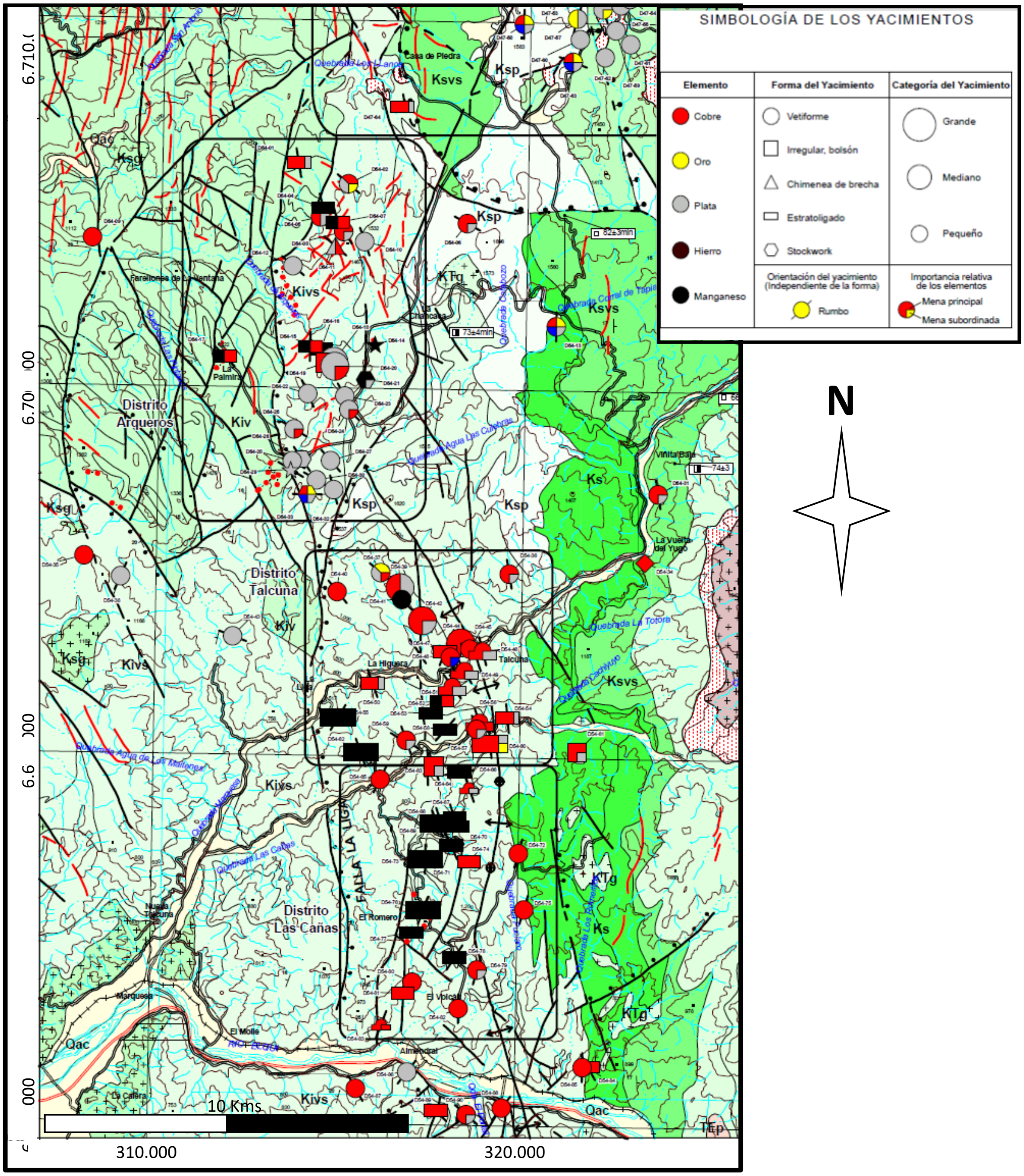


Figure 4.36. Geological context of the Arqueros, Talcuna, and Las Cañas districts (taken from Jorquera et al., 2012: to see more detail, the reader should refer to the original map).

4.2.3. Talcuna District

It is located in the D1C domain, as defined by Jorquera et al. (2012; Fig. 4.35), and it's accessed by traveling 12 km northeast from the intersection of the Marquesa Valley with the Elqui River. In the district, rocks of the upper and inferior members of the Quebrada Marquesa Formation (Kivs) are recognized; these include: epiclastic breccias, sandstones, calcareous sandstones, andesites and intercalated tuffs and the presence of microdioritic sills and mineralized andesites. This sequence is integrated into the Talcuna anticline, for which the axis of its axial plane is oriented in the NNW direction and extends at least 30 km in the SSE direction (Fig 4.36).

The bedded Mn deposits are located preferentially at the western end of the district and are intercalated within a sequence of tuff, sandstone, tuffaceous sandstones and sedimentary breccias. These deposits extend over the order of hundreds of meters and vary between 0.4 and 1.7 m thick. The mineralogical composition consists of kryptomelanite, pyrolusite, braunite, and, in lesser quantities, oxidized Cu and Ag minerals. The gangue is composed of calcite, and there exists no evidence of alteration in the country rock.

The results of chemical analyses performed on manto ore samples (see the detailed location on the map by Jorquera et al., 2012) show Mn contents greater than 20% in the La Liga mines of Talcuna (D54-55), Alta mine (D54-62), and Balcanes-La Higuera (D54-58). Cu concentrations reach up to 0.56% in the La Liga de Talcuna mine (D54-55) and average 0.23% in the district for these manto type deposits. Ag concentrations reach values of up to 33 ppm in the Alta mine (D54 – 62) and 16 ppm in the La Liga mine in Talcuna (D54 – 55).

4.2.4. Las Cañas District

4.2.4.1. Location and general characteristics

It´s located in the southern portion of the D1C domain, as defined by Jorquera et al. (2012; Fig.4.35); and its access starts in the Marquesa valley, goes up the Las Cañas valley, finally detouring after 10 km after the town of Marquesa. Mn extraction activity in the district dates back to the middle of the XX century in the El Romero mine (D54-76) and the San Carlos mine (D54-73) (Biese, 1950).

Similarly as in the Talcuna district, rocks recognized in this district belong to the upper and lower members of the Quebrada Marquesa Formation (Kivs) (Fig. 4.36); these include breccias, epiclastics, sandstones, calcareous sandstones, andesites, intercalations of tuff and the presence of microdioritic sills and mineralized andesite. The entire sequence is part of the Talcuna anticline, and, in general, the manganese deposits that have been exploited are found on the western flank of this structure. The same is true in the Talcuna district.

This district contains strata-bound deposits of Mn, Cu-Ag and Cu and vein-body deposits of Cu with subordinate Ag.

The strata-bound deposits of Mn, concordant with the stratified beds of the Quebrada Marquesa Formation (Kivs), present strikes varying from 25°W to 32°E and dips measuring less than 25° W. They measure up to 600m long; their average extension is 300 m long. The beds are no more than 2.2m thick, having an average thickness of around 0.7m. These deposits have been exploited via galleries less than 50m long. The beds are intercalated with a sequence of rocks including: sandstones, volcanic sandstones, limonites, limestones, volcanoclastic breccias, and tuffs.

The mineralogical composition of the ore in these deposits includes: pyrolusite, psilomelane, and oxidized Cu minerals as well as trace amounts of magnetite, chalcopyrite, bornite and Ag-sulfosalts. The gangue is primarily calcite with lesser quantities of barite and gypsum. In general, there is no evidence of alteration in the country rock and, occasionally, it is possible to observe clays, chlorite, and trace amounts of sericite.

Chemical analyses of ore samples indicate Mn concentrations greater than 20%. Cu concentrations are less than 846 ppm. Ag content values reach as high as 43 ppm, where the average for the district is 24 ppm (Jorquera et al., 2012).

4.2.4.2. Geology and sample collection at the district Las Cañas

At the Las Cañas district outcrops of a sequence of volcanic rocks, andesites, with marine calcareous intercalations (mainly neocomian) are present, which, given their facies and age, would be the direct lithoestratigraphic equivalent to the Bandurrias Formation (Kb) (Fig. 4.37).

South of 29°45´S latitude the Bandurrias Group sequence was divided (Aguirre and Egert, 1965) in two concordant units: the Arqueros Formation and the Quebrada Marquesa Formation.

In the district rocks assigned to the Quebrada Marquesa Formation are present, upper and lower members. The sequence includes epiclastics breccias, sandstones, calcareous sandstones, andesites, and intercalations of tuffs. Additionally, in the northeast sector of the district, mineralized microdioritic and andesitics sills exist. The stratified sequence in this district is folded, the Talcuna anticline fold, same as in the "Talcuna" district, recognized here. This formation contains in its mid-section, presence of manganese mantos; in some places near the base it presents calcareous sandstone lenses with fossil fauna (Fig. 4.37).

Andesitic volcanic rocks outcrop to the west, with intercalations of ryolitic lavas and sedimentary rocks that belong to the Los Elquinos Formation. To the north it is intruded by rocks of the Central Belt that correspond to granites (Fig. 4.37).

During the visit and inspection of the district one sample was collected from the stockpile material from a pit stripping sector. The material comes from centimetric to metric mantos intercalated with red sandstones and mudstones (Fig. 4.38).

4.2.4.3. Prospective Geochemistry from Las Cañas District

The one sample collected at Las Cañas District, obtained from mineral stock pile of pit stripping of a mineralized manto was analyzed by means of an Aqua Regia Digestion and ICP-OES analysis (AQ370, BUREAU VERITAS MINERALS LABORATORIES) for a total of 24 elements.

From the analytical result, it is worth mentioning that the chemical analysis of sample LC-01 taken at Las Cañas District indicates a concentration of manganese of over 20% (Table 4.14). The concentrations of Co and Cu are reported low, 0,003% and 0,053% respectively.

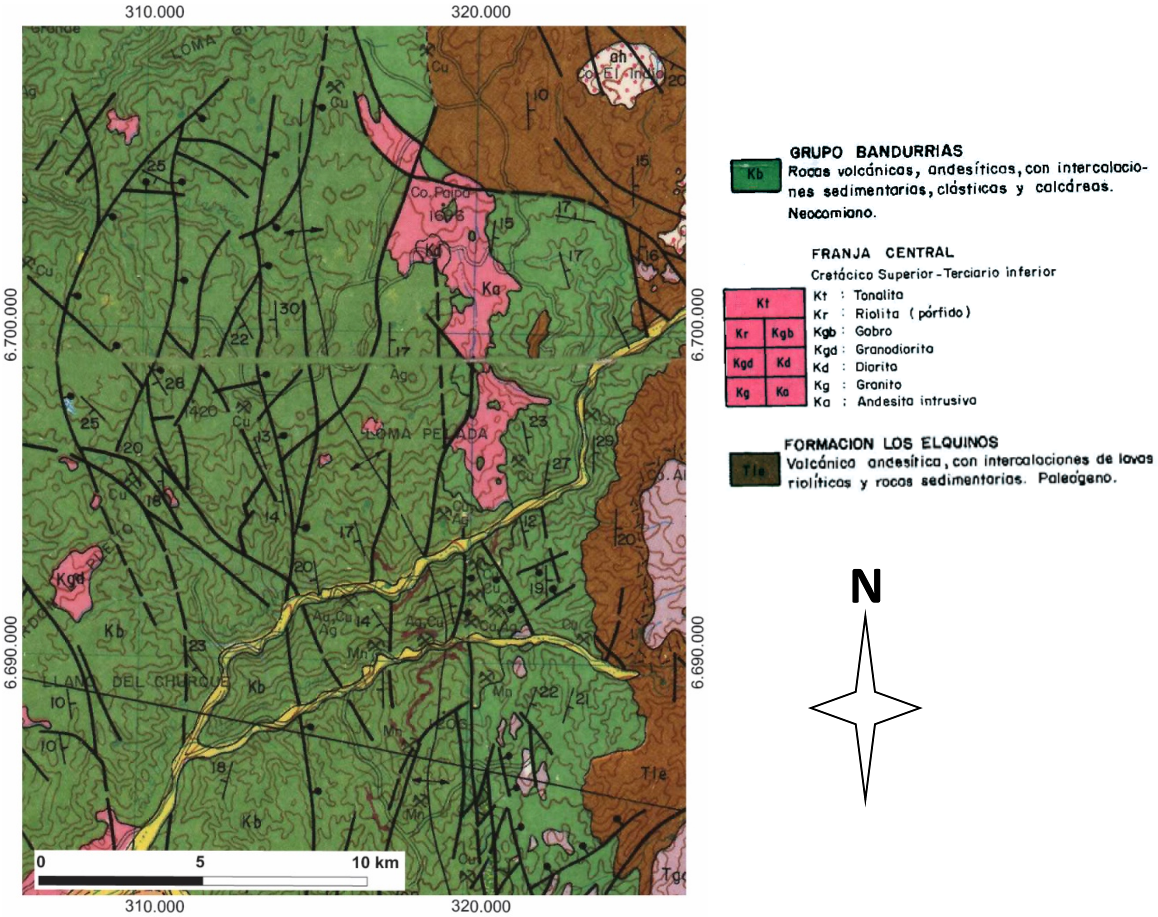


Figure 4.37: Modified geological map of Vallenar Sheet and north part of La Serena 1:250.000 (Moscoso et al., 1982). Red dot indicates sample collection site.

Figure 4.38: Manganese levels intercalated in the volcanosedimentary sequence of the Arqueros Formation (left) and outcrop details of worksites developed for selective extraction (right).

The geochemical analysis results from the sample collected in this district is concordant with the results described in the previous records, confirming manganese as the single ore in these deposits, low to no potential for secondary minerals/elements as potential relevant sub product.

Table 4.14: Analytical results of Co, Cu, Mn, Fe, As and S of the sample collected at Las Cañas District. The rest of the elements are presented in Annex 2. Mine shaft and worksite pit name and summarized description of samples.

Muestra	Co %	Cu %	Mn %	Fe %	As %	S %	MINA	DESCRIPCIÓN - MUESTRA
LC-01	0,003	0,053	>20,00	2,16	0,04	0,19	S.I.	Mantos centimétricos a métricos intercalados con areniscas y fangolitas rojas

S.I.: No information

4.2.5. Corral Quemado and Fragua Districts

4.2.5.1. General characteristics of the Corral Quemado District

It is located in the metallogenic domain D1, as defined by Jorquera et al. (2009; Fig.4.39) and lies approximately 20 km north of the town of Samo Alto. The deposits in the district contain manto and lense like bodies of manganese intercalated in a sequence of rocks including sandstones, limonites and tuffs of the Quebrada Marquesa Formation (Kivs; Fig. 4.40). According to Peebles and Klohn (1970), the English company Chilean Manganeso Co. started exploitation of manganese in Chile in 1884 in the mines of the Corral Quemado district and in others in the Atacama and Coquimbo regions. Exploitation continued until 1904. The activity in the district was renewed in 1937 (González, 1938) with a production of 10,000 mT of Mn and an average ore grade of 46%. In 2009, the deposits in the district were exploited by Manganesos Atacama S.A. in the Loma Negra and Toda la Vida mines (D61-05). Loma Negra was exploited as an open pit mine, and possessed 7 million tons of proven reserves having an average ore grade of 12% Mn. There are references to Toda la Vida mine showing 250,000 tons of proven reserves with an average ore grade of 41% Mn, which were extracted by means of an underground mine that produced 5,000 mT/month. In the district, ores with grades varying from 30% - 52% Mn have been mined.

The floor of the sequence hosting the manganese-containing mantos, lenses and bands correspond to a volcanic breccia made from an andesitic lava containing amygdales and, locally, coarse-grained volcanic sandstones with abundant chlorite. The roof of the sequence is composed of shales, sandstones and yellow-colored fetid limestones deposited in a lacustrine environment. According to Ruiz and Peebles (1988), in the western sector of the district the mineralization is associated with stratified deposits of travertine. The manganese-rich beds are kilometers long, generally sub horizontal, and between 2 and 6m thick. Decimeter-thick bands with higher grades are recognized. The higher potential zones belong to the sectors where the mantos are found folded and repeated (Ruiz and Peebles, 1988). The ore minerals in the deposits include braunite, pyrolusite and, to a lesser degree, manganite and psilomelane (Aguirre and Mehech, 1964). Braunite occurs mixed in with the gangue (primarily piemontite and calcite) and tends to form banded textures with alternating bands of braunite and gangue. Braunite also occurs as small patches associated with pyrolusite (Aguirre and Mehech, 1964). The pyrolusite is the only mineral present in the Loma Negra mine; it forms as needles mixed in with the gangue and occasionally forms with a slightly banded texture, composed of alternating mineralized bands and gangue. Occasionally, pyrolusite forms lamellar structures or is disseminated in the gangue as fine grains (Aguirre and Mehech, 1964). The results of a chemical analysis performed for an ore sample presents a MnO content greater than 20%, a CaO content greater than 21.5%, and an Fe2O3 content of less than 1% (Aguirre and Mehech, 1964).

4.2.5.2. General characteristics of the Fragua mining District

It is located about 8 km NE of the town of Samo Alto, within the D1 Domain as defined by Jorquera et al. (2009; Fig. 4.39). Mining operations in the district are currently paralyzed. Similarly to the Corral Quemado district, manganese minerals were exploited since 1884 by the English company Chilean Manganese Co. They were transported on the backs of mules and in carriages to the Recoleta station, of the Longitudinal Railway (Peebles and Klohn, 1970). This activity ceased in 1904 and then was reinitiated in the end of the 1930s. In the Las Breas mine, reported production was 288 t from 1945 to March of 1946 and ore grades were over 48% Mn (Villavicencio, 1946). Mining activity was developed in manganiferous deposits stratigraphically equivalent to those recognized in the Corral Quemado district that were intercalated with siltstones, chert layers, limestones, tuffs, sandstones and andesites from the Quebrada Marquesa Formation (Kivs; Fig. 4.40).

The manganiferous beds extend hundreds of meters and have thicknesses in the range of 0.5 – 1.5m; they strike NE and have variable dips not exceeding 25°. The mineralogical composition of the ore in the deposits consists of: braunite, manganite, pyrolusite, hausmannite and psilomelane. Braunite and manganite predominate (Aguirre and Mehech, 1964). These authors indicate that, additionally, the observed braunite a) is mixed in with manganite and pyrolusite, b) occurs in crystals forming compact groups lacking gangue, c) occurs as small euhedral crystals disseminated in the gangue (quadrangular and pentagonal cross-sections), d) fills pores in concentric bands alternating with calcite, e) occupies spaces between pores, and f) occurs as large crystals with faces occasionally replaced by pyrolusite and/or containing inclusions with pyrolusite needles showing a slight orientation. Manganite occurs as fill in fractures and, in part, as radially-oriented acicular crystals forming clumps and, occasionally, are associated with, apparently replacing, braunite. Additionally, manganite occurs surrounding crystals of hausmannite; is found forming, together with braunite, parts of concentric bands; or occurs as fine crystals disseminated in the gangue. Pyrolusite occurs in trace quantities and is found mixed in with braunite, as inclusions in manganite and braunite, and, in part, as acicular crystals included within the braunite. In some samples, this replacement happens in two preferential directions. The hausmannite and the psilomelane occur in trace quantities. The gangue is principally calcite, quartz, and an unidentified red mineral, extremely fine in nature (Aguirre and Mehech, 1964). In polished sections taken from the Las Breas mine, nodules of manganese have been identified surrounding hematite. Some of these nodules present nuclei of hematite and their diameter vary, measuring in the range of 0.01 – 0.05 mm and forming, in some sectors, ´chains´ of nodules. A chemical analysis performed in an ore sample from the district indicated a manganese concentration no greater than 16.5%, a CaO percentage of 51.91%, and a SiO2 percentage of 27.31%. The Cu concentration is low (less than 0.03%), and Au and Ag is found below the limit of detection.

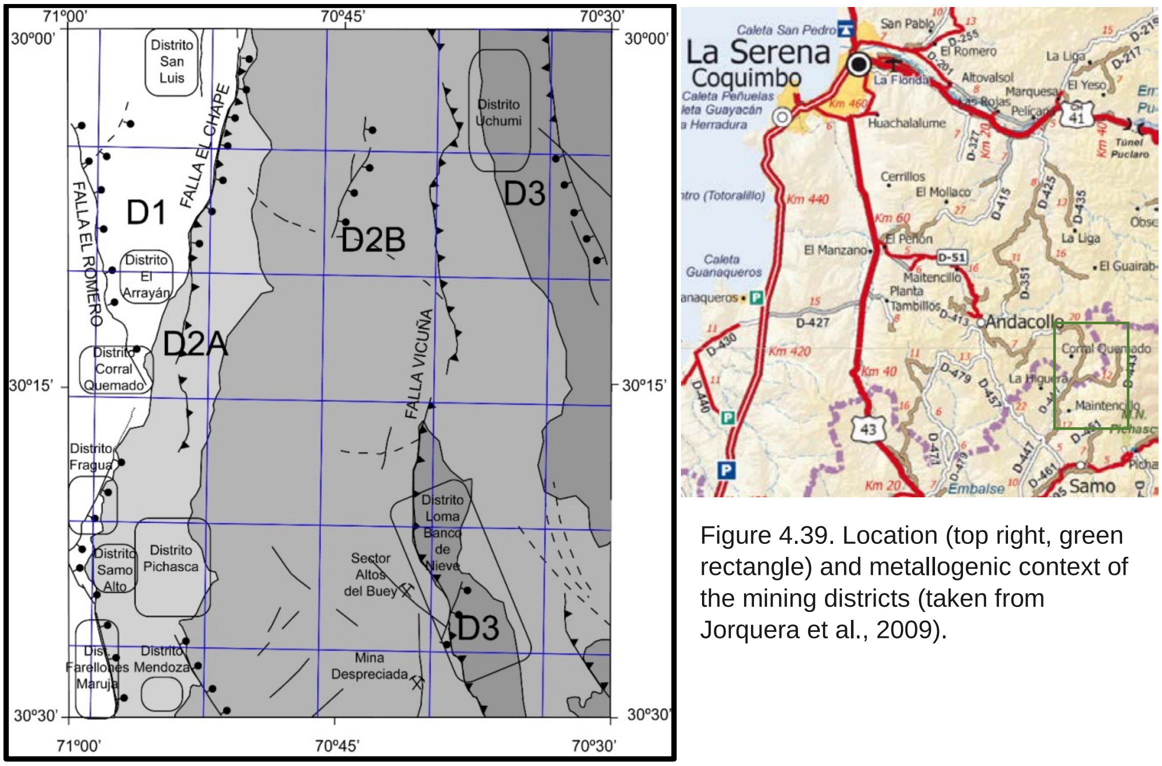


Figure 4.39. Location (top right, green rectangle) and metallogenic context of the mining districts (taken from Jorquera et al., 2009).

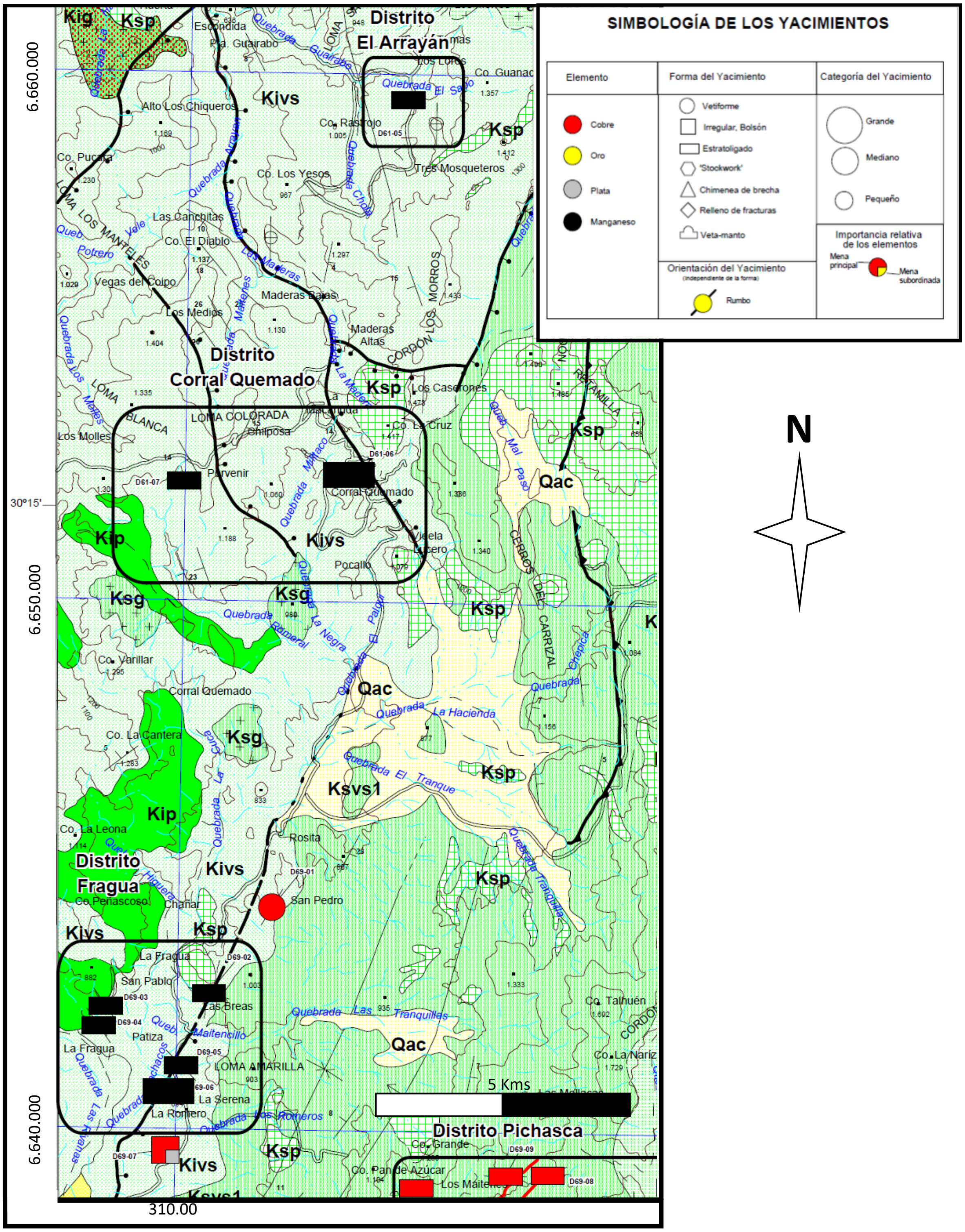


Figure 4.40. Geological context of the mining districts (taken from Jorquera et al., 2009: to see in more detail, the reader should refer to the original map).

4.2.5.3. Geology and sample collection at the Corral Quemado and Fragua Districts

At the Corral Quemado and Fragua districts the main outcrops are rocks of the **Quebrada Marquesa Formation** and **Strata of the Quebrada La Totora** (Fig. 4.41). These are intruded by Dacitic – Andesitic Hypabyssal Intrusives and Andesitic to Dacitic Hypabyssals.

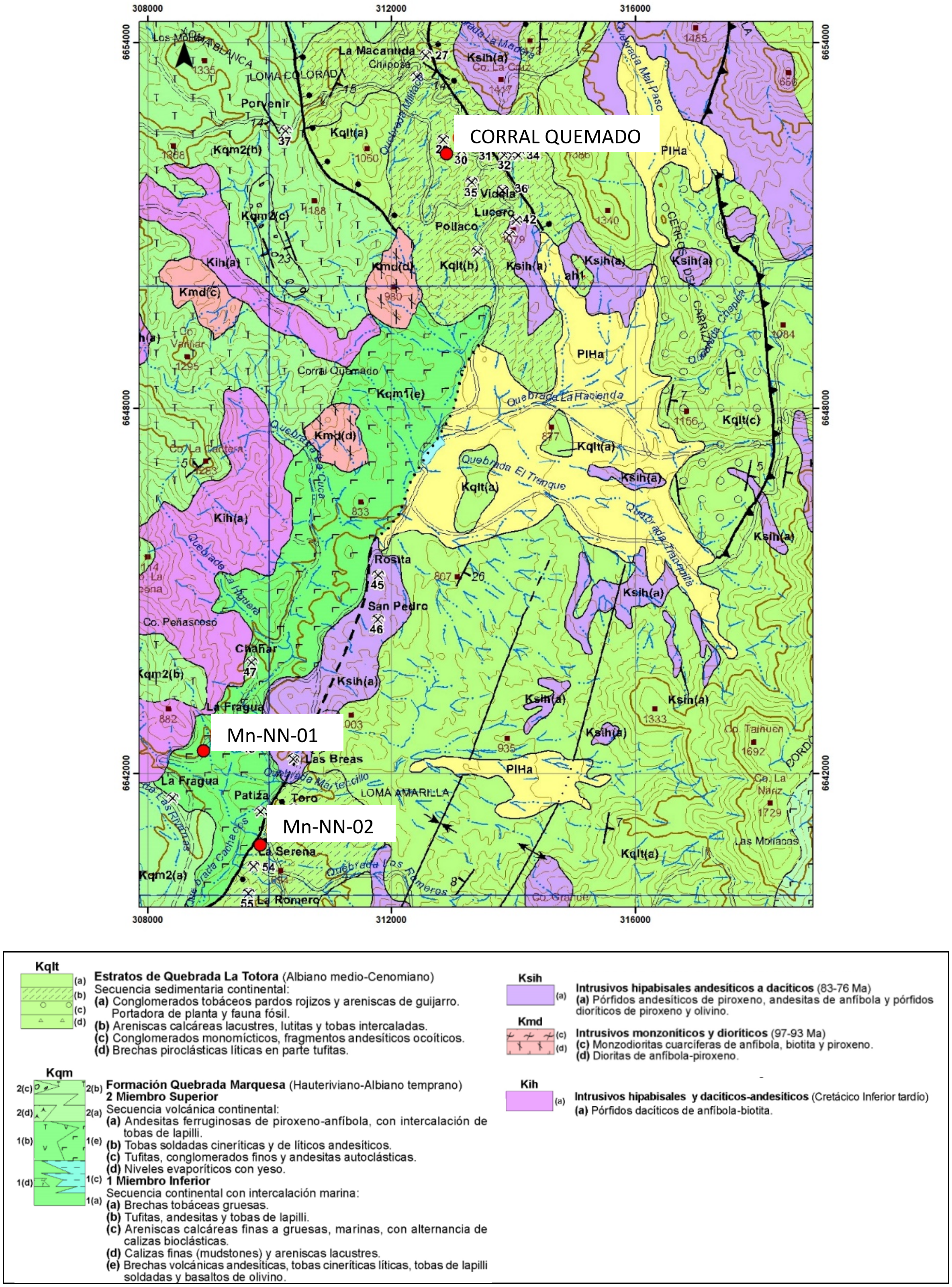
The Quebrada Marquesa Formation (Kqm; Fig. 4.41) was defined by Aguirre and Egert (1965) as a clastic sedimentary sequence of predominantly continental and volcanic origin, with a marine intercalation at the base. In the district these rocks outcrop in a sequence that includes sandstones, siltstones, tuffs, volcanoclastic rocks, andesitic volcanic breccias with lithic fragments, with manganese lenses and mantos. The rocks of the Strata of Quebrada La Totora (Kqlt; Fig. 4.41) outcrop to the east, in contact through a normal fault (El Chape fault) with the Quebrada Marquesa Formation. These correspond to a continental sequence, formed by conglomerates with intercalations of sandstone (kqlt (a)), calcareous sandstones and lacustrian shales (kqlt (b)), monomictic conglomerates (kqlt (c)) and lithic breccias (kqlt (d)). The group of rocks previously described is intruded to the west by stock type hypabyssal rocks and seams of dacitic and microdiorite-andesitic composition, formed mainly by amphibole-biotite dacitic porphyry with varieties of amphibole dacitic porphyry, amphibole-biotite dacitic porphyric, and aphanitic and flow dacitics. The felsic minerals present alteration to sericite, smectite and caolinite, and amphibole is replaced by calcite and hematite-magnetite (Hypabyssal Dacitic-Andesitic Intrusives Kih (a) Fig. 4.41). Other intrusive rocks present are Monzonite and Diorite (Kmd; Fig. 4.39) formed mainly by gray pinkish amphibole-biotite and amphibole-piroxene quartz monzodiorites. To the east they are intruded by Hypabyssal Andesitic to Dacitic Intrusives Kih (Fig. 4.41) formed mainly by piroxene andesitic porphyry, amphibole-piroxene andesites and pyroxene and olivine porphyry diorite.

Sample collection at the Corral Quemado district

A total of 3 samples (CQ1 to 3) were collected at the Corral Quemado district, these from the Corral Quemado mine and surroundings. The mine is located near the Corral Quemado hill. In this area rocks of the Strata of Quebrada La Totora outcrop, these intruded by the Hypabyssal Andesitic to Dacitic Intrusives (Fig. 4.41). The samples were collected from the process disposal gravels resulting from separation of manganese oxide minerals; from the fine separation process disposal material of manganese oxide minerals, and directly from material from the manganese oxide mantos (massive-scoreauceous-banded-clastic).The sample collection sites are presented in Fig. 4.42.

Sample collection at the Fragua district

At the Fragua district two samples were obtained from two different sites. The first sample was collected from an abandoned mine, name unknown (sample FR-01 in Mine-NN-01). This place is located immediately SE of the Fragua mine (Fig. 4.41). In this location rocks of the Quebrada Marquesa Formation outcrop, intruded by the Hypabyssal Andesitic to Dacitic Intrusives to the east and by the Hypabyssal and Dacitic Intrusives to the west (Fig. 4.41). Samples were taken directly from manganese oxide mineral mantos within a sequence of red volcanic sandstones (Fig. 4.43).



Kqlt

Estratos de Quebrada La Totora (Albiano medio-Cenomiano)
Secuencia sedimentaria continental:
(a) Conglomerados tobáceos pardos rojizos y areniscas de guijarro. Portadora de planta y fauna fósil.
(b) Areniscas calcáreas lacustres, lutitas y tobas intercaladas.
(c) Conglomerados monomícticos, fragmentos andesíticos ocoíticos.
(d) Brechas piroclásticas líticas en parte tufitas.

Kqm

Formación Quebrada Marquesa (Hauteriviano-Albiano temprano)
2 Miembro Superior
Secuencia volcánica continental:
(a) Andesitas ferruginosas de piroxeno-anfíbola, con intercalación de tobas de lapilli.
(b) Tobas soldadas cineríticas y de líticos andesíticos.
(c) Tufitas, conglomerados finos y andesitas autoclásticas.
(d) Niveles evaporíticos con yeso.
1 Miembro Inferior
Secuencia continental con intercalación marina:
(a) Brechas tobáceas gruesas.
(b) Tufitas, andesitas y tobas de lapilli.
(c) Areniscas calcáreas finas a gruesas, marinas, con alternancia de calizas bioclásticas.
(d) Calizas finas (mudstones) y areniscas lacustres.
(e) Brechas volcánicas andesíticas, tobas cineríticas líticas, tobas de lapilli soldadas y basaltos de olivino.

Ksih

Intrusivos hipabisales andesíticos a dacíticos (83-76 Ma)
(a) Pórfidos andesíticos de piroxeno, andesitas de anfíbola y pórfidos dioríticos de piroxeno y olivino.

Kmd

Intrusivos monzoníticos y dioríticos (97-93 Ma)
(c) Monzodioritas cuarcíferas de anfíbola, biotita y piroxeno.
(d) Dioritas de anfíbola-piroxeno.

Kih

Intrusivos hipabisales y dacíticos-andesíticos (Cretácico Inferior tardío)
(a) Pórfidos dacíticos de anfíbola-biotita.

Figure 4.41: Modified geological map of the Geology of the Vicuña – Pichasca Area, Coquimbo Region, 1:100.000 (Pineda and Emparan, 2006). The sample locations are marked in red dots.

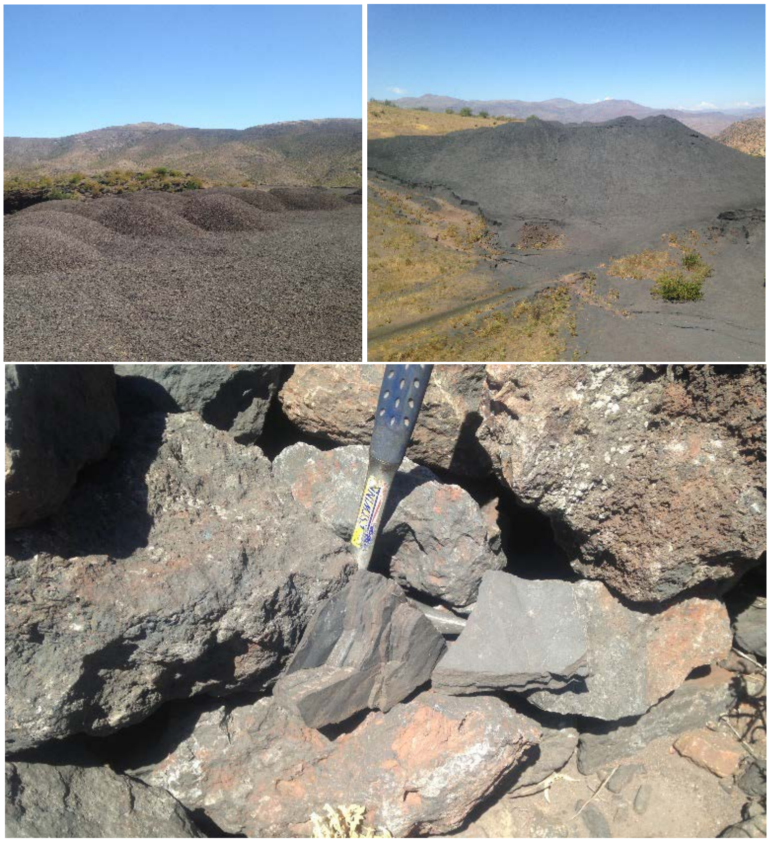


Figure 4.42: Sample of gravel (top left) and fine disposal material for separation of manganese oxide minerals (top right) and variety of manganese oxide mineral rocks from stripping piles (bottom).

In the south zone of the Fragua district a second sample was collected (sample FR-02 at Mine-NN-02). The sample was collected at a mine without name, located south of the Fragua mine (Fig. 4.39). At this site rocks of the Quebrada Marquesa Formation outcrop, intruded by Hypabyssal Andesitic to Dacitic Intrusives to the east and by Hypabyssal Andesitic and Dacitic Intrusives to the west (Fig. 4.39). The sample was collected directly from manganese oxide mantos interstratified within red volcanic sandstones (Fig. 4.41).

Figure 4.43. Mine Sample NN-02 taken from a manganese manto interstratified in red sandstones (magnet pen).

4.2.5.4. Prospective Geochemistry of the Corral Quemado and Fragua Districts

Corral Quemado District

Samples collected at the Corral Quemado District were obtained from different rock piles from mine strippings within the Corral Quemado mine site, these analyzed by means of an Agua Regia Digestion and ICP-OES determination (AQ370, BUREAU VERITAS MINERALS LABORATORIES) for a total of 24 elements.

From results it is worth mentioning that the chemical analysis of samples from Corral Quemado indicated a concentration of more than 20% manganese (samples CQ2 and CQ3; Table 4.15). The concentrations of Co and Cu are reported to be low, less than 0.003% and 0.07% respectively.

Table 4.15: Analytical results of Co, Cu, Mn, Fe, As and S for the samples collected from the Corral Quemado District. The rest of the elements are presented in Annex 2. Mine shaft and worksite pit name, and summarized description of the samples.

Muestra	Co %	Cu %	Mn %	Fe %	As %	S %	MINA	DESCRIPCIÓN - MUESTRA
CQ1	0,002	0,05	11,91	0,85	<0,01	0,23	CORRAL QUEMADO	Granza (gravilla) del descarte de proceso separación de Ox.Mn
CQ2	0,002	0,069	>20,00	1,14	0,01	0,22	CORRAL QUEMADO	Material fino del descarte de proceso separación de Ox.Mn
CQ3	0,001	0,042	>20,00	0,59	0,01	0,14	CORRAL QUEMADO	Mantos de Ox.Mn (Masivo-Escoreáceo-bandeado-clástico)

Fragua District

Samples collected at the Fragua District were obtained directly from mineralized mantos, these analyzed by means of an Agua Regia Digestion and ICP-OES determination (AQ370, BUREAU VERITAS MINERALS LABORATORIES) for a total of 24 elements.

From the analyses it is worth mentioning that the results for samples of the Fragua District indicate a concentration of more than 20% of manganese (samples FR-02 Table 4.16). The concentrations of Co and Cu are reported to be low, less than 0.003% and 0.1% respectively.

Table 4.16: Analytical results for Co, Cu, Mn, Fe, As and S, of the samples collected at the Fragua District. The rest of the elements are presented in Annex 2. Mine shaft and worksite pit name, and summarized description of the samples.

Muestra	Co %	Cu %	Mn %	Fe %	As %	S %	MINA	DESCRIPCIÓN - MUESTRA
FR-01	0,002	0,105	17,05	0,37	0,04	0,13	S.I.	Mantos de Ox.Mn en secuencia de areniscas volcánicas rojas
FR-02	0,002	0,058	>20,00	1,22	0,04	0,24	S.I.	Mantos de Ox.Mn en secuencia de areniscas volcánicas rojas

4.2.6. El Arrayán mining District

It is located 8 km north of the Corral Quemado district and some 30 km north of Samo Alto town (Fig. 4.39). Systematic exploitation of the deposits in this district began only after 1907. In 1970, the only registered medium-scale activity was by the Santo Tomas II mine; meanwhile, other smaller mines in the district only registered artisanal exploitation (Peebles and Klohn, 1970). Exploitation labor in the district was concentrated on the manganese mantos located in zones where there were manganese bands or lenses concordant with the stratification of layers of red volcanic sandstones

(Peebles and Klohn, 1970). In some sectors of the district, they exist in association with travertine deposits found within a 2 – 10m thick sequence of sandstones and tuffs. Similarly, as with Corral Quemado, the underlying rock in the sequence that contains the manganese layers corresponds to amygdaloidal lavas and the roof consists of a lacustrine sedimentary sequence with a characteristic yellow color (Ruiz and Peebles, 1988). The volcano-sedimentary sequence shows folds and faults. The fold axes are oriented NNE and dip NS with variations to the east and west. These rock sequences have been assigned to the Quebrada Marquesa Formation (Kivs) and are intruded by porphyry bodies striking generally NE (Ksp). The manganese-rich beds present strikes oriented generally in the NE direction, and they dip variably between 13°-15°E. The mineralogical composition of the ore in the deposits includes, principally: braunite, pyrolusite, and, in lesser quantities, psilomelane and manganite (Peebles and Klohn, 1970). Pyrolusite is an alteration product of braunite and is present in euhedral crystals with a clearly defined cleavage that sometimes presents a radial structure. Also common is a botryoidal, colloform texture. Psilomelane is present, for the most part, with a colloform, banded texture (Aguirre and Mehech, 1964). The gangue is primarily composed of calcite and baryte.

Peebles and Klohn (1970) showed ore grades varying between 42 and 48% manganese in the Santo Tomas II mine.

4.2.7. Mining resources for manganese

The deposits from the Corral Quemado district were exploited by Manganesos Atacama S.A. in the Loma Negra and Toda la Vida mines until the year 2009. Loma Negra was an open-pit mine; proven reserves were estimated at 7 million tons of Mn ore with an average ore grade of 12%. Toda la Vida reported 250,000 tons of Mn proven reserves with an average ore grade of 41% and produced, through underground exploitation, 5,000 tons a month (Jorquera et al., 2009). This company, a subsidiary of CMP, is the owner of the Corral Quemado, Fragua, El Arrayán, San Carlos, La Liga Alta, Lambert and Arqueros mining operations.

Beyond the boundaries of the Coquimbo region, there are existing studies known for two manganese exploitation projects located in the XV Region of Arica and Parinacota. They have been described in section 3.2 of this study and are briefly mentioned below:

- *Project Minera Mar y Cielo*, where the existence of 600 million tons (Mt) of Mn with an average ore grade of 47% has been determined (Camin Ingeniería y Explotación Minera, http://www.camin.cl/proyectos-mineros/proyecto-manganeso/).
- *Project Manganeso Los Pumas*, located in the community of Putre, where, given a cut-off grade of 7.8% Mn, 18.3 million tons have been estimated and more than 5.4 million of tons of reserve are inferred. Owned by Minera Hemisferio Sur, this project is currently awaiting legal resolutions. It should be mentioned that the Council of Ministries recently revoked permission for the project on environmental grounds.

Other manganese resources of similar characteristics are found in the Sierra de La Bandera district of the Atacama region, for which there are no known records referencing this resource (Vivallo et al, 2008). Additionally, vein-body type and disseminated manganese deposits are known to the northeast of the city of Copiapó in the Sierra el Chulo and the Portezuelo del Inca sector; they have been exploited on a small mining operations scale (Díaz et al., 2006).

5. Extractive metallurgy and the recovery of cobalt and manganese

5.1. Mineralogy of cobalt and its extractive metallurgy

The concentration of cobalt in the terrestrial crust is estimated at 22 ppm and generally occurs in disseminated form in almost all situations in which it forms a metallic mineral in conjunction with copper, nickel, lead, zinc, iron, silver, and manganese. It is also found in mineral and sea water.

The cobalt minerals are grouped as: arsenates, arsenides, sulfides, sulfoarsenides, and oxides. The principal minerals with economical cobalt content are described in Table 5.1.

Table 5.1 Common minerals with cobalt content that are found in economic mineral deposits.

Name	Group	Formula
Erythrite	Arsenate	$Co_3(AsO_4)_2 8H_2O$
Skutterudite	Arsenide	$(Co,Ni)As_3$
Cobaltite	Sulfosalt	CoAsS
Carrolite	Sulfide	$Cu(Co,Ni)_2S_4$
Linnaeite	Sulfide	$Co^{2+}Co_2^{3+}S_4$
Asbolane	Oxide	$(Ni,Co)_{2-x}Mn^{4+}(O,OH)_4 nH_2O$
Cobaltiferous Pyrite	Sulfide	FeS_2 + Co

The economic concentration of cobalt can be found in four different geological environments (Table 5.2), and, generally, the majority is found in association with the mining industry as by-products of other base metals, preferentially nickel and copper. Large quantities of cobalt occur on the oceanic floor, contained within manganese nodules and cobalt-rich crusts; however, these are not economically viable with present-day technologies and under current economic conditions.

5.1.1. Mineral processing - extractive metallurgy

As previously mentioned, almost all of the cobalt that can be obtained worldwide comes as a more or less important by-product of copper and nickel exploitation.

Depending of the deposit size, ore grade of the mineralization, morphology and closeness to the surface, the deposits are exploited in subterranean or open-pit mines, or a mixture of the two.

In general, the process of concentrating the cobalt-rich minerals is performed by milling the ore rock and separating the cobalt-containing minerals from the gangue minerals using physical and chemical processes.

In this case, the production of cobalt as a by-product of other metals depends on the extractive processes of the principal metal. The process used in the extraction of cobalt generally starts after the primary metal (usually nickel or copper) has been concentrated and extracted. There exist three basic processes used in the extraction of cobalt: hydrometallurgy (includes the extraction by solvent, electrolysis, and electroplating), pyrometallurgy, and vapometallurgy.

Table 5.2 Summary of the principal types of cobalt deposits.

Type of Deposit	Genetic formation processes	Economic ore grade	Major examples
Hosted in sediments	From diagenetic processes in coastal environments, close to coastal lines or in saline lakes, where the ocean water sulfates are reduced to sulfides causing metallic elements to concentrate in the sediments.	0,1 – 0,4%	Tenke Fungurume, Democratic Republic of Congo; Mt Isa, Australia
Hydrothermal/magmatic	Minerals are precipitated in the country rock due to hydrothermal fluids of magmatic-hydrothermal origin.	0,1%	Bou Azzer, Morroco; Keretti, Finland
Magmatic sulfides	The immiscible liquid phase for sulfides is concentrated in the magmas and crystallized. This phase collects and concentrates metallic elements rich in cobalt.	0,1%	Norilsk, Russia; Sudbury, Ontario, Canada; Kambalda, Australia
Laterite	Tropical climates cause the weathering of silicates and cobalt sulfides in ultramafic bodies, causing the enrichment of cobalt in the residual rocks.	0,05 – 0,15%	Koniambo Massif, New Caledonia
Manganese nodules and cobalt-rich crusts found on the ocean floor	Concentrations of ferromagnesian oxides in the ocean floor	2,5%	Currently not economically viable

The principal sources of cobalt ore are sulfides. For these, the copper and cobalt minerals are processed in a conventional manner to produce a copper-cobalt concentrate. This is done using flotation to separate a concentrate rich in cobalt for further treatment afterwards during the refinement of cobalt. The flotation process uses pneumatic and mechanic agitation to produce air bubbles that bring the mineral particles to the surface. Different reagents are used to attract the cobalt minerals, instead of copper minerals, to the bubbles. The cobalt concentrations, which may reach up to 15% Co, are later processed using pyrometallurgical or hydrometallurgical extractive processes.

For the hydrometallurgical processes, the metals are separated by the differences in their solubility and in basis of their electrochemical properties in solution. One of the more common hydrometallurgical processes is high pressure acid leaching (PAL).

5.1.2. Extraction and refinement

The cobalt contained in a copper concentrate is oxidized together with iron during the final conversion to copper anodes. After this process, the cobalt enters into the slag layer, which can be treated separately and usually is done using an electric furnace. This cobalt is then recovered by slag reduction by adding carbon to form a copper-iron-cobalt alloy. During nickel smelting, the larger percentage of cobalt is recovered as a precipitate from solution during the electrolyte refining process for nickel, usually in the form of a cobalt hydroxide. During nickel smelting, the cobalt begins to oxidize before nickel and may be recovered from the final converter slag. During the ammonium pressure process for leaching nickel, cobalt is recovered from solution by hydrogen reduction under pressure. In refineries that use nickel matte chloride leaching, solvent extraction is used to eliminate cobalt directly from the solution. The resulting concentrated solution, after purification, is appropriate for the recovery of cobalt during electrolyte extraction.

The electroplating process involves filtration, heating and a series of electrolyte states of the metal-rich solution. Cobalt precipitation occurs over stainless steel plates to form high-purity cathodes. The acid is then recycled.

Vapometallurgy is a modern process effective for the processing of lateritic ores. For the case of lateritic nickel, cobalt is recovered as a by-product when it is present.

In the pyrometallurgical processes, heat is used to separate the metals based upon their different points of fusion, densities and other physical and chemical characteristics of each element. These methods are used principally for magmatic sulfide ores. For these ores, the recovery of the maximum possible amount of concentrate is based on the smelting process. Cobalt is usually extracted from these smelted products using electrolytic processes, for which anodic cobalt is dissolved in the electrolytic cell and ionic cobalt is deposited with some impurities on the cathode in the lower part of the cell.

For copper-cobalt mineral concentrates, roasting is performed under controlled conditions in order to transform the majority of the cobalt sulfide into a soluble sulfate, all the while minimizing changes in copper and iron in their water-soluble states. The product of this process is leached, the resulting solution is treated in order to eliminate the copper and iron, and finally the cobalt is recovered for electrolysis. If the minerals of copper and cobalt are in an oxidized state, the copper can be eliminated by electrolysis in a sulfuric acid solution and the cobalt can be precipitated from the electrolyte by adjusting the acidity of the solution. The cobalt is eventually obtained in its metal state using electrolysis.

The cobalt concentrate derived from arsenide minerals can be roasted in the same way as sulfide concentrates in order to eliminate arsenic as an impure arsenic trioxide. Alternatively, it can be leached, and cobalt can precipitate out with hydrogen - a similar process as how nickel sulfide concentrates are made.

5.2. Mineralogy of cobalt and its extractive metallurgy in Chile

The following information presented here is based principally on the following reports: *Adaptación de Tecnología para la recuperación de Cobalto desde Minerales y Relaves* (Adaptations in

Technology for the recovery of Cobalt from Minerals and Tailings) (INTEC, 1988) and *Proyecto Cobalto – Freirina* (Cobalt-Freirina Project) (Geoexploraciones, 1983).

The occurrence of cobalt in Chile, as mentioned in the previous chapters, is found included principally in the structure of pyrrhotite; arsenopyrite; constituting sulfoarsenides; and arsenides like cobaltite, smaltite, skutterudite, safflorite, and cobaltiferous pyrites, among others; or, perhaps, in the form of arsenates like erythrite. With the exception of erythrite, these minerals are normally associated with chalcopyrite, pyrite, sphalerite, galena and silver sulfides.

The extraction of metallic cobalt is complex and there exists various processes in order to isolate it from the gangues and other useful metals that have previously been mentioned. From an economical point of view, cobalt is a by-product derived during the extraction of other metals (ex. copper, nickel).

5.2.1. Cobalt concentration processes

The principal processes for concentrating cobalt minerals are gravitational concentration, magnetic separation and flotation.

Among the processes involved in gravitational concentration, the following may be considered: the use of jig concentrators, vibrating tables, spirals and heavy media. The use of these processes for gravitational concentration depends upon the characteristics that each mineral presents. These include, fundamentally: high specific gravity of the mineral being concentrated, a difference between the specific densities of the mineral and the gangue (usually differences of 1 gr/cm^3 or more), and the liberation size of the mineral of interest after grinding, among others.

The mineralogical species of cobalt (like cobaltite, safflorite, skutterudite, and smaltite) may be easily separated from a gangue made of quartz and biotite (2.7 gr/cm^3) by gravitational methods. The mineral erythrite, on the other hand, has a low mass and gravitational separation is not apt for this mineral; however, it is possible to separate it from a gangue of quartz using a magnetic concentrator, given the high magnetic susceptibility ($53,2 \times 10^6$ cm^3/gr) that this species presents.

In general, the cobalt arsenides have a high specific gravity with values between 6.5 and 7.2 gr/cm^3, a property that makes them suitable for separation from the gangue using gravitational methods like jig concentrators, spirals and vibrating tables.

Arsenide and sulfoarsenide mineral concentration by flotation presents difficulties, given that these ores normally associate with chalcopyrite and iron sulfides like pyrite and pyrrhotite. Chalcopyrite may easily be separated out by flotation as long as it is not inter-grown with iron and cobalt minerals. There are difficulties to perform the separation of the cobalt-bearing species from the iron-bearing sulfides, because under flotation both species present similar behaviors, especially in the case of cobaltite.

5.2.1.1. Magnetic separation

The magnetic separator is a technology that takes advantage of the higher magnetic susceptibility that some minerals posses in order to separate them from other minerals not possessing this quality. Minerals containing cobalt, like pyrite [$(Fe,Co)S_2$], may come to contain up to 22% of cobalt. This mineral is a species of non-magnetic iron, and, therefore, it is possible to separate it from other species of iron that present this quality to some extent like phyrrotite, magnetite, and hematite. These cobalt-bearing minerals tend to be associated in different proportions with other copper species like chalcopyrite, chalcocite and bornite. Subjecting these materials to the process of magnetic separation allows concentration of a useful product with a lower mass and a greater ore grade with respect to the original head grade. Another time when this methodology should be used is in the presence of erythrite or other cobalt oxide species that may be present in greater proportions as an alteration product of the primary ore.

5.2.1.2. Concentration by flotation

In the processing of ore rocks with sulfide copper minerals and cobalt by-products, the concentration of minerals using flotation is normally performed in the following way:

- General flotation of copper-cobalt from a pre-concentrate obtained using gravitational methods.
- Selective flotation of copper (the cobalt sinks) from the overall concentrate obtained from the previous step of general flotation.

For polymetallic deposits, the potential of the deposit for different metals (Cu, Ni and Co) and the relationship between them that will be obtained in the concentrate should be determined in order to define the best recovery process for cobalt.

5.2.2. Extraction processes for cobalt

5.2.2.1. Pyrometallurgical processes

In this process, the concentrate obtained from the flotation plants is partially roasted, mixed with Coke and limestone, and smelted in electrical furnaces. In this procedure, a matte of copper-cobalt is obtained. At a later stage, the matte is treated in convertors obtaining metallic copper and a cobalt-rich slag. This slag, containing cobalt, copper and iron, is smelted with Coke in order to obtain an alloy of these metals that will be separated by means of chemical processing.

The following chemical processes may be involved: roasting with sodium chloride, electroplating, pressure hydrometallurgy, and solvent extraction.

5.2.2.2. Roasting with sodium chloride

The concentrate is roasted with sodium chloride followed by leaching to remove the produced chlorides. Using chalk as an intermediary, the solution is purified by precipitating out some of the arsenic and iron. The cobalt is precipitated out with Ca-hypochlorite. With this reagent, first the cobalt and then the nickel (when present) precipitates out, a procedure from which first a cobalt oxide can be retrieved and then a nickel oxide. Afterwards, the oxides can be reduced by smelting with carbon. This way a relatively pure cobalt product can be achieved (98%).

5.2.2.3. Electroplating

The concentrate is leached with sulfuric acid, and copper and cobalt is obtained as impure copper and cobalt cathodes; this occurs by the means of complex leaching systems and successive electroplating of the copper and cobalt. The cathodes are then purified by smelting using the proper flux material.

5.2.2.4. Pressure hydrometallurgy

The raw material used may be a mineral, a concentrate, a matte, or some by-product from other processes. The reagent used during leaching may be ammonium or acid, and the oxidizing element may be either air or oxygen. For materials with high cobalt content, the use of an acidic leach is preferred; ammonium is preferred for use with materials presenting a high content of nickel or copper and a low content of cobalt.

Once the leaching process has occurred, the solids are separated from the solution, and then the solids are purified. The most common impurities are products of secondary reactions and excess reagents. The first element that precipitates out is Cu, then Ni when present, and finally, Co.

Using hydrogen, the copper tends to precipitate out forming copper with either iron or cobalt, or a copper-iron and cobalt mixture may be formed when precipitating out from defect states. In other cases, the hydrogen can react to form hydrogen sulfide.

Nickel can precipitate out by electrolysis and by using hydrogen, forming nickel ammonium sulfate.

Using hydrogen, the cobalt can precipitate out as metallic cobalt or crystallize as cobalt ammonium sulfate.

The diversity of precipitation alternatives will depend on the relationship in which the Cu, Ni and Co elements are found in solution.

5.2.2.5. Solvent Extraction

Studies exist for analyses tested on mineral materials taken from marine nodules, where this technique has most often been employed. At first glance it appears the most promising in terms of an extraction process for complex Cu, Ni and Co minerals; however, the publications have not been very specific regarding their findings to date. There is also no information regarding operation costs to perform this process on an industrial scale.

5.3. The mineralogy of manganese and its extractive metallurgy

5.3.1. Mineralogy

Manganese is the twelfth most abundant element in the terrestrial crust with an average concentration of 0.1%. It is the fourth most abundant metal in commercial use. In nature, manganese is found in the form of oxides, carbonate and silicates. The deposits are generally of sedimentary origin with oxide layers rich in interstratified iron. The most common of the manganese minerals is pyrolusite (MnO_2); but it can also be found as rhodochrosite ($MnCO_3$), rhodonite ($MnSiO_3$), braunite ($3Mn_2O_3MnSiO_3$), black manganite ($MnO(OH)$) and alabandite (MnS). Only those minerals containing more than 35 percent of manganese are considered commercially exploitable, but the lack of high-grade manganese minerals has had an influence on the development and use of low-grade manganese. According to the Federal Stockpile program of the United States (National Materials Advisory Board, 1976), processed manganese minerals or concentrates must have a rather high content of manganese and minimal quantities of impurities. The impurities may include oxides of other metals, like iron, that are reduced together with the manganese during the smelting process; non-metallic elements like phosphorous, sulfur and arsenic; and "gangue oxide" metals like silica, aluminum, calcium oxide and magnesium that, with the exception of silica, generally remain in the slag after smelting.

Another potential source of manganese are the manganese nodules or concretions of iron-manganese that have been found on the ocean floor. Usually, they contain 30 – 36% Mn. Although the nodules are found in both oceans (Atlantic and Pacific), they are most common in the Pacific Ocean. These nodules are of interest since they contain significant concentrations of nickel, copper and cobalt, as well as large quantities of manganese, which may make them an important source for metals in the future.

The majority of the manganese production worldwide is concentrated in four countries: Australia, China, Gabon and South Africa. Up to 90% of the global reserves of manganese are found in these four countries as well as in Brazil and the Ukraine. Almost 70% of the global reserves of manganese are contained in the Kalahari district of South Africa (Palisade Research, 2017).

5.3.2. Mining operations and concentration

Here, some of the processes used worldwide for the extraction and subsequent refining of manganese minerals are described (Michaud, 2016).

5.3.2.1. The extraction of manganese minerals

The extraction of manganese minerals is performed normally in open-pit mines. After the extraction of the material, the process continues with mechanical concentration of the manganese and the elimination of impurities: metallic, non-metallic, volatiles, etc. In order to extract the impurities, the minerals are washed and then subsequently are removed using a transporter belt that carries the mineral to the processing plants. Some of the metallic impurities are: Fe, Pb, Cu, Zn, and Ag; the non-metallic impurities are: Sulfur, Phosphorous, and volatile impurities like: H_2O, CO_2, organic material, and gangue (SiO_2, Al_2O_3, CaO, MgO, BaO). The manganese material is divided according to size. The coarse-grained material gets sent to the plant and subsequently to primary and secondary crushers; the fine material is allowed to collect by sintering (Fig. 5.1).

5.3.2.2. Gravity concentration of manganese minerals

Gravity concentration of manganese minerals can be performed using jig concentrators, vibrating tables, Humphrey spirals, Reichert spirals, and Birtley densimetric tables, among other methods.

The process using jig concentrators requires air to be pushed through the apparatus; the gangue is eliminated over an ascending slope; and the heavier minerals (Mn) settle to the bottom where they are concentrated.

5.3.2.3. The concentration of manganese minerals by magnetic separation

This technique is based upon the separation of iron minerals from manganese minerals by taking advantage of the magnetic properties of the first.

Figure 5.1: An example of manganese mineral extraction (Source: Maxtech Ventures en Palisade Research, 2017).

5.3.2.4. The concentration of manganese minerals by flotation

One of the processes used in order to concentrate manganese from the silt fraction produced during the grinding and separation processes is flotation. The flotation treatment consists of thickening the manganese minerals in a Spiral Rake Tray Thickener.

The flotation circuit is designed to treat three classes of manganese ore.

1.- Minerals with a high calcite gangue.

2.- Minerals with a mixed calcite and siliceous gangue.

3.- Minerals with a high siliceous gangue.

Types 1 and 2 ores require a pre-float treatment to eliminate the calcite as froth. The calcite should be eliminated before the manganese because it will float with the manganese; thereby giving a low grade manganese concentrate. In order to do this process, the consumption of large quantities of reagents is necessary, and they vary with each type and grade of mineral.

The following reagents can be mentioned for the two cases: ores with calcite gangue minerals and ores with siliceous and aluminum gangue minerals.

(1) Carbonate-gangue-ores: The carbonate gangue, having minerals like calcite, floats first with fatty acids, using an alkaline pulp and a starch or yellow dextrin to inhibit the formation of manganese oxide. The pulp is then acidified and the manganese oxide floated in an oil emulsion.

(2) Siliceous- and aluminum-gangue-ores: This gangue floats in a circuit containing sulfuric acid and using the previously mentioned combustible oil emulsion.

5.3.3. Extraction and refining

Pure manganese is produced by hydrometallurgical and electrolytic processes, while the ferromanganese and silico-manganese are produced by the smelting of ores in a blast furnace or, more commonly, an electrical furnace. The higher manganese oxides (MnO_2, Mn_2O_3 and Mn_3O_4) can be reduced to manganese oxide (MnO) by carbon monoxide, but this lesser oxide can be reduced to metal only at elevated temperatures by carbon. Smelting is further complicated by the action of gangue oxides. For example, silica, an acid compound, can combine with MnO and inhibit reduction - a problem that can be corrected for by using ores rich in basic components like lime and magnesium or by the addition of basic fluxes like roasted limestone. However, this generates more slag that tends to dissolve the manganese and diminish the quantity of recovered metal in the smelted mass. Additionally, depending on the temperature of fusion and the acidity or basicness of the slag, the silica can be reduced to silicon and enter in the smelted metal.

5.3.3.1. Leaching processes

The typical processes of leaching used are reductive chemical steps, including bioleaching and electro-leaching. The purification, separation, and final recovery are done in procedures like solvent extraction, electrolysis, and electroplating.

5.3.3.2. Electrolytic process

Manganese electroplating is an important process for the production of high-purity electrolytic manganese (Zhang, 2007). For applications that prefer pure manganese, the manganese ores are roasted in order to obtain an MnO calcine, and this is dissolved in sulfuric acid in order to form a manganese sulfate solution (Figure 5.2). The iron (III) is typically eliminated by precipitation with hydroxide at a pH of 3-4 and other impurities like Ni, Co, Cu, and Zn are eliminated by precipitation with sulfides. The $MnSO_4$ solution that results can be used for the production of electrolytic manganese. The purified solution feeds an electrolytic cell and, upon application of an electrical current, the manganese is deposited in layers a few millimeters thick over a stainless steel cathode sheet with a purity of 99.5% manganese. The cathodes are periodically extracted and the manganese deposits are removed by hammering. The flakes are heated to 500°C in order to remove hydrogen gas, resulting in a manganese metal product with 99.9% purity.

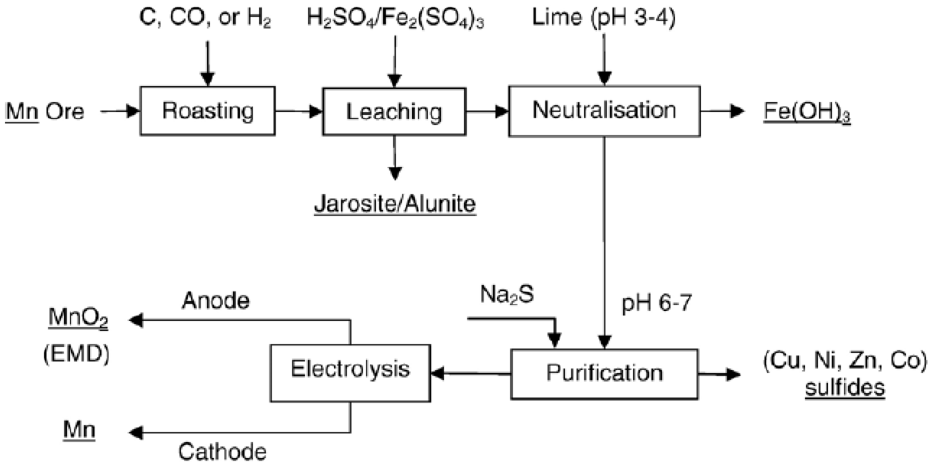


Figure 5.2: The conventional process of electrolytic Mn production (Zhang, 2007).

5.3.3.3. Production problems

Although the manganese ore is not a non-metallic resource, the use of flotation in its extraction is similar to the procedure for non-metallic ores. The reagents for non-metallic ores are used to float impurities like calcite, and there exists reagents that are used to concentrate the manganese minerals and reject the silica and aluminum minerals to the tailing.

5.4. Mineralogy of manganese and its extractive metallurgy in Chile

In Chile, manganese production stopped in 2009 (Source: Comisión Chilena del Cobre, Anuario de Estadísticas del Cobre y otros Minerales 1996 – 2015). This production was associated with the company Manganeso Atacama, which exported 50% of its production to the Argentinian market and fabricated high- and medium-carbon manganese ferroalloys. The closure of the production was due to the lack of demand for these products from this company in the market (as reported to the SVS by the general manager of the Compañía Minera del Pacífico at that time, Mr. Erick Weber). The mining company maintains its mining properties: Corral Quemado, Fragua, El Arrayán, Romero, San Carlos, La Liga Alta, Lambert and Arqueros, all located in the Coquimbo region.

Manganese mineral exploitation was initially conceived in order to mine and export massive amounts of high ore grade manganese minerals. These minerals were highly valued by the steel industry during the past century. Currently, these mineral resources are exhausted or are scarce and difficult to explore. The way to extract the mineral was primarily in subterranean mines; for a few deposits, the mineral was extracted in open pit mines.

From the previous chapters, it can be deduced that the principal manganese minerals that occur in Chilean deposits are braunite ($3Mn_2O_3MnSiO_3$, 50 – 60% Mn), and pyrolusite (MnO_2, 63,2% Mn); those found in lesser quantities are manganite ($Mn_2O_3H_2O$, 62,4% Mn), psilomelane ($BaMn_9O_{18}2H_2O$, 40 – 60% Mn, varying in Ba, K and Na content according to the impurities), and hausmannite ($MnMn_2O$, 72% Mn). They are associated with gangue minerals like calcite ($CaCO_3$), piedmontite ($2Ca(Al, Fe, Mn_3)(OH)Si_3O_{12}$), and baryte ($BaSO_4$), among others.

In the last period, the exploitation of medium grade manganese from deposits was done principally to satisfy the demand created by manganese ferroalloy processing, like high carbon ferromanganese produced by the company Minera Manganeso Atacama.

6. Discussion and Conclusions

Hereunder a discussion about the potentials that exist in Chile for the exploration and exploitation of cobalt and manganese is presented. It is important to mention that for the purpose of carrying out an evaluation of the potential existing resources in Chile for other metals, comparisons with the great copper mining or gold mining industries should be avoided, because the mineral resources for cobalt or manganese are considered non-conventional ores, or sub products of other mining activities.

6.1. Potential mineral resources for cobalt in Chile: primary ores or sub products

Chile is rich in metallic mineral deposits, especially copper; the origin of this goes back to the beginning of the tectonic – magmatic evolution on the Andean margin in Paleozoic times. The ore deposits and the metallogenic evolution are related to a long history of subduction along the convergent margin of the tectonic plates in Chile, the types of ores and their distribution controlled by tectonic and magmatic conditions in time and space. The main types of ores and distribution, from the oldest to the most recent are described hereunder (Maksaev et al., 2007):

- Paleozoic: Porphyry copper, all small and low grade, non-economical in Chile.
- Upper Jurassic: Strata bound copper deposits, copper vein deposits and gold and silver vein deposits.
- Lower Cretaceous: Porphyry copper of discreet occurrence; iron-apatite (IOA) type deposits; iron-oxide copper-gold deposits (IOCG); stratabound copper deposits; copper and iron skarn deposits, and gold-copper (base metals) epithermal and mesothermal vein deposits.
- Upper Cretaceous: Gold-copper and silver vein deposits of discreet occurrence and minor occurrences of small and low grade porphyry copper deposits.
- Paleocene: world class porphyry copper deposits, gold and silver epithermal vein type deposits and minor occurrences of copper breccia chimney deposits.
- Upper Eocene – Lower Oligocene: Supergiant to behemothian porphyry copper deposits.
- Miocene: Precious metals epithermal and porphyry gold deposits, and supergiant to behemothian porphyry copper deposits.

The distribution of cobalt mineralization known and mined in Chile occurs along the Chilean Iron Belt, deposits that are hosted in paleozoic methamorphic rocks as well as in intrusives, volcanic rocks and in less degree sedimentary rocks of lower Cretaceous age, in a volcanic arc environment along the Coastal Mountain Range of the regions of Atacama and Coquimbo. There is also knowledge of historic cobalt mining from mineralization in the area of El Volcán – Cajón del Maipo, Metropolitan Region, these deposits hosted in rocks of an extensional basin environment of Cenozoic age.

Based on the main types of metallic mineral deposits in Chile, the only documented occurrences of deposits with primary cobalt ore are located in the arc and back-arc environment of the lower Cretaceous. These occur in the Chilean Iron Belt, all along the Coastal Mountain Range in the regions of Atacama and Coquimbo, hosted mainly along the Atacama Fault System, and to a lesser degree extends to volcanic and sedimentary rocks of Central Chile (El Volcán-Cajón del Maipo, Metropolitan Region; Fig. 6.1, marked in red rectangles), mineralization hosted in Cenozoic rocks.

Cobalt and cobalt minerals have a close affinity with copper, nickel, arsenic and iron sulfides, minerals that commonly form mineral associations in hydrothermal deposits. Given this affinity all of the iron deposits could have potential for cobalt sulfide/arsenide minerals, particularly those that present areas rich in arsenides/ arsenic sulfide minerals. The main types of deposits to evaluate for potential cobalt as sub product are the IOCG type, followed by the IOA type (Fig. 6.1 both types marked in red rectangle) and in lesser degree, the porphyry copper deposits (Fig. 6.2 marked in blue rectangles). The evaluation of credits for cobalt as a sub product is highly dependent of the mineral occurrence and metallurgy, studies that are not carried out regularly as a national mining standard.

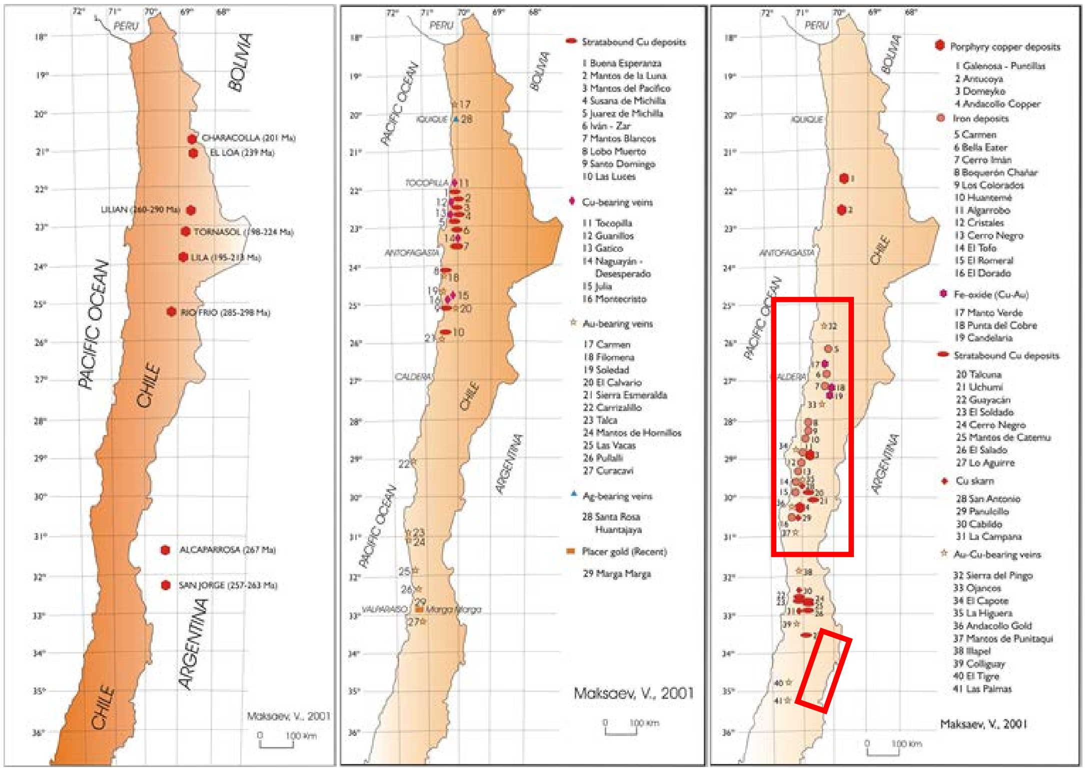


Figure 6.1. Metaallogenic belts, types and distribution of the most important metallic deposits in Chile (Maksaev et al., 2007; Maksaev, 2001). From left to right: Paleozoic; Lower Cretaceous; Upper Cretaceous. Red rectangles: regions known for the occurrence of cobalt as main ore, documented from past mining and/or in which the main deposit could eventually be evaluated for cobalt as sub product.

In addition to the potential cobalt sources as primary or sub product ore, it is worth also mentioning the possibility of recovering cobalt and a diversity of other elements/minerals from tailing bodies. In the case of cobalt, tailings with higher probabilities of having relevant contents would be those originated from the exploitation of IOCG type deposits, for example active and closed tailings in the district of Punta del Cobre-La Candelaria, in the district of Manto Verde, in the district of Tambillos, in the district of San Juan and in tailings from the ENAMI flotation plant in Vallenar. The latter, an active tailing, receives the discards from the processing of minerals of the small mining industry in the province of Huasco and surroundings, as well as ore rocks from the district of San Juan. This plant only recovers copper and gold, therefore other metals of potential interest end up in the tailing.

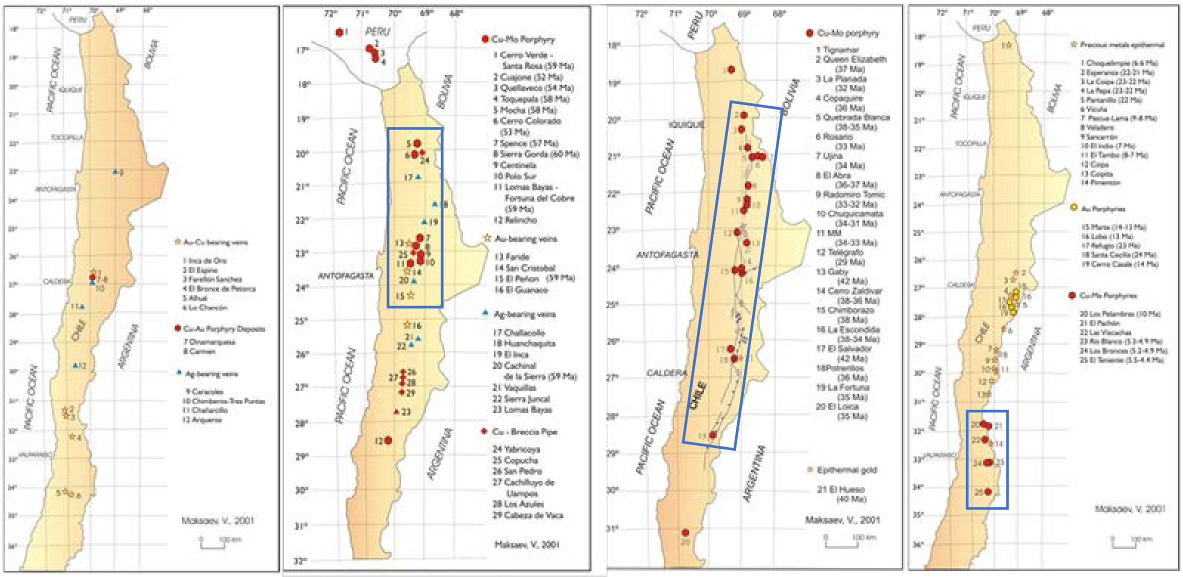


Figure 6.2. Metallogenic belts, types and distribution of the most important metal deposits in Chile (Maksaev et al., 2009; Maksaev, 2001). From left to right: Upper Cretaceous; Paleocene; Upper Oligocene – Lower Eocene; Miocene. Blue rectangles: regions in which porphyry copper deposits could eventually be evaluated for cobalt as sub product.

6.2. Districts with potential for the exploration and eventual exploitation of copper and cobalt.

Based on the bibliographical compilation study, and on-site field studies and sampling, the potential of each mining district is discussed, this in order of priority, from higher to lower potential.

6.2.1. Mining District of San Juan – Atacama Region

The historical background of this district and the geological characteristics described in the literature, corroborated in the visits to the sites plus the sample collections indicate that this district still has potential for exploration in the continuity of mineralization to the north, south and lateral as well as an open potential in depth. Past exploitation did not exceed a depth of more than 100 meters, and even though the predominant mineralization consists of veins and less occurrence of breccias and mantos, the existence of sulfide resources in depth should not be discarded. There is no history of deep drilling in this district and no evidence of this at the site. The current exploration is limited to artisanal exploration mining shafts and/or exploitation mining work.

In the field sampling work at the site was made from mineral piles outside the various mine strippings of the different mine work sites. From the observation of the existing mineral piles, plus historical data, in most of the exploited deposits, it was determined that there is an oxidation zone of variable proportions in which erythrite predominates, together with iron hydroxides and green copper oxide minerals, which extend 30 or 40 meters beneath the surface, transitioning to sulfide zones. In these zones a local secondary enrichment is described, with an increase of the ore grades between 6 – 8% Co, in conjunction with a high enrichment of Cu. This would indicate that the historically mined deposits can expect a good deepening potential, with hypogene mineralization grades that even though are lower than at the oxidized zone, together with copper could justify the incorporation of new resources and exploitation areas.

Based on the results of chemical analysis of samples the presence of cobalt in all of the area visited is corroborated, together with high concentrations of copper in almost all of the samples. These results confirm the historical data as well as the most recent exploration data (Geoexploraciones, 1983). Given the high concentrations of copper and predominant mineralization of copper minerals, together with the mineralization of cobalt, the San Juan district is considered the most relevant in the region of Atacama, with a high polymetallic potential. Notwithstanding the above, it is important to indicate that the total resources, based on the type of predominant mineralization, veins, breccias and manto bodies, would certainly not exceed the dimensions of the medium size mining industry. On the other hand, an additional challenge will be the processing of polymetallic ores, with a metallurgical recovery for at least Cu and Co as the most important ores and potential sub products for Au and Ag. The results of the present study establish that the zone has an interesting economic potential for copper production (as main ore) and cobalt as secondary ore or sub product (credit).

Another positive aspect of the San Juan district is the existence of the Quebradita and Cobaltera Plants, where the samples collected from the plants indicate important mineralization remnants for Co and Cu. The leach pad gravel samples from the La Cobaltera plant and the feeding samples to the Quebradita plant indicate concentrations of 0.211% and 0.189% Co. Associated to these samples it is worth mentioning high concentrations for copper, 3.765% reported for the Quebradita plant and 1.223% for the La Cobaltera plant, as well as values of more than 0.19% As for both samples. These remnant resources require study and evaluation.

6.2.2. Tambillo District – Coquimbo Region

Under a historical perspective this district was one of the most important cobalt producers nationwide. Even though the predominant mineralization is copper, it is accompanied by iron and cobalt mineralization. The existing mineralization in this district is present in veins, breccias and mantos, the most extensive bodies being the mantos. Currently in this district there is mineral exploitation, extraction and processing oriented to the production of copper, with more or less credit for gold. Several old and active mines have reached depth levels of 400 m. On the surface, even though there is an oxidized zone, the processes of secondary enrichment do not produce a relevant level of supergene mineralization.

The different types and styles of mineralization were confirmed during field work at the sites, carried out together with sampling of mine work sites, mostly from mineral piles from mine strippings. The geochemical analysis results indicate that the samples from the Minillas Mine present the highest concentrations of Co, one sample with 0.45% and two samples with Co that exceeded the upper detection limit (>1%). The concentration of Cu reported for these samples is over 0.7%. In other samples from the district, there are high concentrations of copper (>2%) and iron (>40%). Some samples indicate high concentrations of As (1.76% and 9.31%) and of S (1.51% and 4.63%). The geochemical study results can be associated with the occurrence of sulfide minerals such as chalcopyrite, pyrite, arsenopyrite, along with minerals such as cobaltite and/or minerals such as cobaltiferous arsenopyrite, and in areas of supergene oxidation, erythrite.

The geochemical analysis results and inspections at the site confirm the existence of relevant mineralization of cobalt. However, copper mineralization is notoriously more abundant, reason why for a long time this district has been exploited basically for copper. It is worth mentioning that in this district there are mineral bodies rich in magnetite, with iron concentrations of over 40%. Gold exists at a trace level, representing a sub product or credit in the present copper exploitation.

The same as with the San Juan district, the mineralization in this deposit is of polymetallic type, Cu, Fe, Co (Au), among other elements of interest. It is necessary to characterize the present ore rocks and determine technological modifications at the processing plant that will enable the sequential or joint recovery of the main ores (Cu, Co) and sub products (Fe, Au). The present mineralization and hydrothermal alteration suggest IOCG type ores, with the magnetite bodies featuring a similarity with IOA type mineralization, with calcosodic alteration and abundant presence of apatite megacrystals.

In this district, even though exploitation has been carried out for a very long time, reaching important depths in the mining levels, the evidence of potential IOCG type mineralization suggests that the district still has potential for exploration, this towards adjacent properties to the north, south and west of the district, as well as for underground in-depth exploration.

The results of the present study and of the updated information, establish that this zone has an interesting economic potential for copper production (main ore) and cobalt as secondary ore or sub product (credit). The possibility of iron and gold recovery as sub products is not discarded.

It is worth mentioning that there is one active and several abandoned tailings in the district. All of these tailings deposits must be evaluated for their potential for recovery of cobalt minerals, as well as a diversity of other minerals of potential economic interest.

6.2.3. La Estrella Mine –El Zapallo District, Region of Atacama

La Estrella mine, in the mining district of El Zapallo, adjacent to Hot Chili’s Productora project, presents alteration and mineralization typical of IOCG deposits. Mineralization is associated with pervasive replacements of volcanic rocks by biotite potassic alteration, mineralization consisting of massive magnetite, in conjunction and overprinted by sulfide mineralization, mainly pyrite, chalcopyrite and possibly cobalt sulfide, sulfoarsenide and arsenide minerals. There is also important gold mineralization in this deposit, in occasions with concentrations of over 16 g/t (South World Report, 2011). The mineralization is presented in massive mantos, veins and breccia replacements. The present exploration shafts and drifts have intercepted massive mineralization horizons at depths of more than 30 m. At this mine there is accumulation of stockpiles, and even though the purpose of its exploitation and extraction has been for its shipment to the ENAMI processing plant in Vallenar, metallurgical recovery of these polymetallic ores is presently under evaluation and study, as to determine the best way of recovering Cu, Fe, Co, Au and potentially other elements of interest.

The visit to this mine and the samples collected indicate that Co values are over 1,500 ppm and copper values in average exceed 2%. The iron concentration is in average higher than 35% together with sulfur values over 20%. These values would indicate that the mineralization at the La Estrella Mine is mainly conformed of sulfides, chalcopyrite and pyrite, with existence of massive bodies of magnetite as well. The concentrations of arsenic are low, generally below the detection limit, for which cobalt present in this deposit should be associated to cobaltiferous pyrite and/or chalcopyrite, or to cattierite traces (cobalt sulfide).

The results of the studies carried out in this district establish that this zone has an interesting economic potential, with copper as main ore, and cobalt as secondary ore or sub product (credit). It is worth mentioning the high concentrations of iron, an important part in the form of magnetite, and the high concentrations of gold and nickel. The existing polymetallic mineralization existing in this deposit represents a challenge for extractive metallurgy.

6.2.4. Other deposits evaluated for Cobalt

During the development of this present study, other mining districts were studied and visited in which a relevant potential for cobalt as ore, either primary or secondary, was not determined, only in some cases potentially recoverable as a sub product (credit). Hereunder is a list with a brief description of these districts.

- Las Merceditas District, El Volcán, Cajón del Maipo, Metropolitan Region. Even though this is an old district where cobalt was once exploited, during the inspection at the site it was not possible to find any former mining extraction worksites to validate the existence of mineralization in veins or other bodies. The existence of an old tailing, waste dumps, as well as an old loading ramp is all that remains from this old mine. Even though the geochemical results indicate high concentrations of Cu and less Co, as well as high concentrations of Fe, the expectations of large volume IOCG type mineral bodies are low. However, potential exploration and mining of small or medium scale should not be discarded.

- Upper Maule Valley, Maule Region. In this zone there is evidence of iron mineralization with less Cu, Co and Au, in replacement mantos, veins and breccias. Even though concentrations of Cu and Co are low, the high concentrations of Fe and the presence of sulfide and oxide iron mineralization, suggest the likelihood of an IOCG type environment. Given that the information available for this zone is limited, possibilities of polymetallic type mineralization (Fe, Cu, Au, Co) should not be discarded.

- Boquerón Chañar, Atacama region. The visit and sampling of drill cores at the CAP (CORFO) drill core shed, the description of the samples and the geochemical studies performed, confirm mineralization present in this deposit corresponds to the IOA type. It is worth mentioning the high concentrations of Fe with concentrations exceeding 40%, and magnetite as the predominant ore mineralization, with lesser existence of sulfide minerals. Despite that the concentrations of Cu and Co are low at this deposit, and given that the main ore to be considered should be Fe, and that this can be concentrated by means of magnetic recovery, the residual heavy minerals will contain mostly Fe, Cu and Co sulfides, where these latter elements would be enriched in the discards. Therefore, the option of giving aggregated value to this deposit by means of the concentration, separation and recovery of ores in a sequential manner should not be ruled out.

- Los Morteros District, Atacama region. This district does not present major exploration potential, where, even though there is evidence of past exploitation and exploration work, the mineralization present and the analytical results indicate interest only for iron.

6.3. Districts with potential for exploration and eventual exploitation of manganese

In the study regions, Atacama and Coquimbo, the manganese mineral exploitation at the historical districts is well known. This exploitation ended recently (2009). Most of the districts studied and visited belong to CAP, through a subsidiary, Manganesos Atacama, owner of Corral Quemado, Fragua, El Arrayán, Romero, San Carlos, La Liga Alta, Lambert and Arqueros. In spite of the fact that in many of these historical districts there are still remnant resources, due to the present market values for this metal, CAP has no particular interest for the exploitation of these deposits. On the other hand, it is worth mentioning the existence of two large manganese exploitation projects in the regions of Arica and Parinacota (Los Pumas and Mar y Cielo), which could easily supply nationwide requirements and also become important exporters. Regardless of the above, these projects have not obtained environmental resolution approvals, and have confronted hard opposition from the local communities and environmental advocate groups.

From the visits at the site and sample collection the following information stands out:

Las Cañas District – Coquimbo region: From the sample collected, it is worth mentioning concentrations of over 20% manganese, with low concentrations of Cu and Co. This data corroborates previous studies reporting ore samples with concentrations of manganese over 20%.

Corral Quemado and Fragua Districts – Coquimbo region: From the samples collected, it is worth mentioning concentrations of over 20% manganese, with low concentrations of Cu and Co in all of the samples. These concentrations indicate a potential for the exploration of Mn.

6.4. Cobalt and manganese exploration, exploitation and metallurgic challenges

As final reference, it is worth mentioning that the existing mineralization of cobalt in the regions of Atacama, Coquimbo and Metropolitan Region, are present in conjunction with other minerals, in particular and most relevant, copper minerals and as potential sub products, iron and gold, among others. To this day there is mining activity at the San Juan district as well as in the Tambillos district, where production is carried out exclusively for copper, without mention of recovery of cobalt or other metals. This scenario implies a waste of resources that could add aggregated value to copper. The need to study in detail the ore mineralogy and potential recoverable sub products for these deposits should be addressed, to evaluate the plant modifications that would make it possible to recover, in a sequential form, the existing polymetallic ores in all of these deposits. Another important aspect is that it is necessary to look into and evaluate these deposits with a polymetallic mineralization perspective, and not only for copper.

Given that in some of these districts these resources have been exploited for copper, it is very relevant to carry out studies of tailing bodies, as to evaluate possibilities of processing and recovering valuable minerals / elements, changing these bodies from environmental liabilities to mining assets.

In reference to the exploitation, processing and extractive metallurgy of manganese, it is worth mentioning that because production has ended and closing of the mines is recent, there is still a possibility of recovering the processing plants. On the other hand, the Los Pumas and Mar y Cielo projects, despite not having environmental approvals for exploitation yet, do present advanced plans for mining extraction and processing, as stated on the publications in their respective webpages.

6.5. Final Comments

Cobalt

In reference to the potential for cobalt in Chile, from the information gathered, historical data and site visits, it can be established that there is economic potential for the different zones studied, based on the concentration of copper as main ore and concentration of cobalt as secondary ore or sub product (credits). In some cases the recovery of sub products such as iron and gold can be added to these ores, with other elements/minerals to evaluate. The polymetallic association observed and determined at the cobalt deposits in Chile is similar to the ones observed with more frequency at the cobalt producing deposits worldwide, a typical IOCG type signature.

With all of the information presented, feasibility of pilot plants in the different districts that include concentration of copper-cobalt minerals and that consider the separation of copper and cobalt from the concentrations and solutions obtained should be evaluated. The recovery of polymetallic ores could make it viable for small to medium mining productions and supply nationwide demand for cobalt, among other metals of strategic interest. It is fundamental to evaluate the possibility of recovery of cobalt from the tailings resulting in the exploitation of IOCG type deposits, such as La Candelaria, Punta del Cobre district, Manto Verde, among others, and of course, the tailings from the historical cobaltifeous districts described.

Finally, even if the concentrations of cobalt in porphyry copper type deposits are low, given that these deposits are of large scale exploitation in the greater copper mining industry, the mineral occurrence, concentrations, distribution and viability of recovering cobalt minerals or cobalt-rich minerals from the mineral processing for copper should be evaluated.

Manganese

In the case of manganese, for the classic districts in the region of Coquimbo, given that its exploitation ended recently and that the closing of the mines is an on-going process, it is not difficult to initiate exploration, exploitation and metallurgic activities. It will depend though on market and competitivity conditions. In the case of the large projects existent in the region of Arica and Parinacota, even if economic production could be achieved according to the technical information submitted by the property and project owning companies, environmental and social restrictions do not allow this to occur to this date.

References

Aguirre, L.; Egert, E. 1965. Cuadrángulo Marquesa. Instituto de Investigaciones Geológicas, Carta Geológica de Chile, No. 15, 92 p., 1 mapa escala 1:50.000. Santiago.

Aguirre, L., Mehech, S., 1964. Stratigraphy and mineralogy of the manganese sedimentary deposits of Coquimbo province, Chile. Apartado. Economic Geology, Vol. 59, p. 428-442. Lancaster, Pa., E.E.U.U.

Aguirre, L. 1970. Cuadrángulo Lambert. Instituto de Investigaciones Geológicas, Carta Geológica de Chile, No. 23, 14 p., 1 mapa escala 1:50.000. Santiago

Arevalo, C. y Welkner, D., 2008. Geología del área Carrizal Bajo – Chacritas, región de Atacama, Escala 1:100.000. Monografías. Sernageomin, Carta Geológica de Chile, Serie Geología Básica: n° 111. 67 p.

Barra, F., Reich, M., Selby, D., Rojas, P., Simon, A., Salazar, E., and Palma, G., 2017. Unraveling the origin of the Andean IOCG clan: A Re-Os isotope approach. Ore Geology Reviews, 81, 62-78.

Bembow, M., 1980. Geología regional y económica de los distritos Astillas y Capote, III región, Atacama, Chile. Memoria de Título, Departamento de Geología, Universidad de Chile. 108 pp.

Biese, W., 1950. Informe sobre el yacimiento de manganeso "El Romero". (Inédito). Caja de Crédito Minero, 41 p. 1 mapa escala 1:10.000 (*).

British geological survey, 2009. Cobalt. Mineral UK. Centre for sustainable mineral development.

CAMCHAL, AHK Business center S.A., 2015. Identificar elementos de valor en residuos mineros (relaves) y evaluar su recuperación como productos comerciales – 13BPC3-19021- Informe Técnico Final. Antofagasta: CORFO.

Caraballo, M., Townley, B., González, E., Riquelme, B., 2017. Elementos de interés económico en relaves Chilenos: Estado del Arte. Informe Corfo, P1, Programas Tecnológicos, Valorización de Relaves. 175 pp.

Carballo, A., 1979. Cobalto, níquel y zinc en piritas y calcopiritas de algunos yacimientos cupríferos en el norte de Chile. Actas Segundo Congreso Geológico de Chile. 18 pp.

Cruzat, A. 1968. Monografía sobre los yacimientos de cobalto chilenos (Inédito). Corporación de Fomento de la Producción-Instituto de Investigaciones Geológicas- Naciones Unidas, 30 pp.

D'Aubarede, G. 1969. Evaluación de los conocimientos existentes sobre Cobalto, Manganeso, Mercurio. PNUD/CORFO/IIRN. Santiago. 259 pp.

Díaz, A.; Lacassie, J.P.; Vivallo, W. 2010. Yacimientos Metalíferos del área Andacollo- Puerto Aldea, Región de Coquimbo. Servicio Nacional de Geología y Minería, Carta Geológica de Chile, Serie Recursos Minerales y Energéticos, N° 31, 28 p., 1 mapa escala 1:100.000.

Díaz, A.; Lledó, H.; Vivallo, W. 2006. Yacimientos metalíferos de la Carta Copiapó. Región de Atacama. Servicio Nacional de Geología y Minería. Serie Recursos Minerales y Energéticos No.26, 30 p., 1 mapa escala 1:100.000. Santiago.

Díaz, A.; Lledó, H.; Vivallo, W., 1998. Yacimientos metalíferos de la Hoja Los Loros, Región de Atacama. Servicio Nacional de Geología y Minería, Mapa de Recursos Minerales de Chile 2: 24 p., 1 mapa escala 1:100.000. Santiago.

Díaz, F.; Bembow, M.; Bravo, N.; Gutiérrez, A.; Montti, S.; Salinas, M.; Vogel, S. 1981. Mapa metalogénico pronóstico de la III Región (Inédito), Corporación de Fomento de la Producción-Instituto de Investigaciones Geológicas, 5 Vols., 6 mapas escala 1:250.000 (*).

Emparán, C.; Pineda, G. 2000. Area La Serena-La Higuera. Región de Coquimbo. Servicio Nacional de Geología y Minería. Mapas Geológicos, No 18, 1 mapa escala 1:100.000, Santiago.

Gelcich, S; Espinoza, C.; Vivallo, W., 1998. Yacimientos metalíferos de las hojas Chañaral y Diego de Almagro, Región de Atacama. Servicio Nacional de Geología y Minería, Mapa de Recursos Minerales de Chile 3: 17 p., 1 mapa escala 1:100.000. Santiago.

Geoexploraciones. 1983. Proyecto Cobalto-Freirina, publicado en: Diversificación de la pequeña y mediana minería, SERPLAC - Atacama. Copiapó.

González, J. 1938. Mineral Corral Quemado. (Inédito), Caja de Crédito Minero, 2 p. (*)

Herrera, M. 2016. Estimación de las altitudes de las líneas de equilibrio en glaciares de montaña para el último ciclo Glacial-Integral en los Andes de Santiago Chile Central. Tesis de Doctorado. Departamento de Geología, Universidad de Chile, Santiago, 202.

Informe South World, 2011. Estudio de diagnóstico geológico distrital Distrito “El Zapallo”, región de Atacama. Informe Final. ENAMI. SW Minning S.A., Noviembre 2011. 35 pp.

INTEC, 1988. Adaptación de tecnología para la recuperación de cobalto desde minerales y relaves. INTEC-CHILE. Corporación de Fomento (CORFO), 204 pp. Santiago.

Jorquera, R., Portigliati, C., Vivallo, W., Díaz, A., 2003. Yacimientos metalíferos de las cartas Castilla y Totoral bajo: región de Atacama, Escala 1:100.000. SERNAGEOMIN, Carta Geológica de Chile, Serie Recursos Minerales y Energéticos (n.23): 32 p., 1 mapa.

Jorquera, R.; Díaz, A.; Vivallo, W.; Astudillo, N. 2009. Yacimientos Metalíferos del área Vicuña-Pichasca, Región de Coquimbo. Servicio Nacional de Geología y Minería, Carta Geológica de Chile, Serie Recursos Minerales y Energéticos, N° 29, 29 p., 1 mapa escala 1: 100.000.

Jorquera, R.; Pizarro, N.; Vogel, S. Díaz, A.; Vivallo, W. 2011.Yacimientos Metalíferos del área La Serena-La Higuera, Región de Coquimbo. Servicio Nacional de Geología y Minería, Carta Geológica de Chile, Serie Recursos Minerales y Energéticos, N° 32, 32 p., 1mapa escala 1: 100.000.

Jorquera, R.; Díaz, A.; Vivallo, W.; Carrasco, R.; Pizarro, N.; Pineda, G.; Vogel, S. 2012 Yacimientos Metalíferos del área Condoriaco-Rivadavia, Región de Coquimbo. Servicio Nacional de Geología y Minería, Carta Geológica de Chile, Serie Recursos Minerales y Energéticos, N° 33, 41 p., 1mapa escala 1: 100.000.

Lacassie, J.P.; Vivallo, W.; Díaz, A. 2016. Caracterización geoquímica de yacimientos metalíferos de la Región de Atacama mediante el uso de redes neuronales artificiales. Servicio Nacional de Geología y Minería, Informe Registrado IR-16-61: 177 p, 1 CD. Santiago.

Lacassie, J.P.; Vivallo, W.; Díaz, A.; Ruiz del Solar, J., 2015. Geoquímica de yacimientos metálicos y de sedimentos, de las regiones de Atacama y Coquimbo, norte de Chile. Actas XIV Congreso Geológico de Chile. 4 pp.

Maksaev, V., Townley, B., Palacios, C., Camus, F. 2007, Metallic ore deposits (Chapter 6). In: The Geology of Chile, T. Moreno, W. Gibbons (eds.), England, p. 181-201.

Maksaev, V., 2001. Reseña metalogénica de Chile y de los procesos que determinan la metalogénesis Andina. Documento inédito, Departamento de Geología, Universidad de Chile. 63 pp.

Manganesos Atacama S.A. 2009. Empresa del Grupo CAP (www.manganeso.cl)(22-01-2009).

Mathur, R., Marschik, R., Ruiz, J., Munizaga, F., Leveille, R., Martin, W., 2002. Age of Mineralization of the Candelaria Fe Oxide Cu-Au Deposit and the Origin of the Chilean Iron Belt, Based on Re-Os Isotopes. Vol. 97, 2002, pp. 59–71

Michaud, L. D. 2016. Manganese Ore Processing. (www.911metallurgist.com/blog/manganese-ore-processing) (24-10-2017).

Moscoso, D.; Nasi, C.; Salinas, P. 1982. Geología de la Hoja Vallenar y parte Norte de La Serena, Regiones de Atacama y Coquimbo. Servicio Nacional de Geología y Minería, Carta Geológica de Chile, No. 55, 102 p., 1 mapa escala 1:250.000. Santiago.

National Materials Advisory Board, 1976. Manganese recovery technology. Report of the "Panel on manganese recovery technology of the committee on technical aspects of critical and strategical materials. 83 pp.

Palisade Research, 2017. Manganese – the third electric vehicle metal no one is talking about. (www.mining.com/web/manganese-the-third-electric-vehicle-metal-no-one-is-talking-about-it-heres-how-to-take-advantage/) (24-10-2017).

Peebles, F.; Klohn, E. 1970. Geología de los Yacimientos de Manganeso de Corral Quemado, Arrayán y Fragua, Provincia de Coquimbo. Instituto de Investigaciones Geológicas, Boletín 27: 58 p.

Peebles, F.; Ruiz, C. 1985. Distribución y Génesis de los Yacimientos estratiformes de manganeso en Chile. Actas 4° Congreso Geológico Chileno, Vol. 3, p. 3-271 - 3-287. Antofagasta, Chile.

Pincheira, M., Rodriguez, M., Helle, S., Kelm, U., Frutos, J., 1997. El cobalto y níquel en sulfuros como indicadores de la fuente de los metales y ambientes de formación de depósitos. Actas VIII Congreso Geológico Chileno. 5 pp.

Pineda, G. y Emparan, C., 2006. Geología del área Vicuña – Pichasca, región de Coquimbo, Escala 1:100.000. SERNAGEOMIN. Carta Geológica de Chile, serie Geología Básica (n.97). 40 p., 1 mapa.

Pizarro, N.; Portigliati, C.; Vivallo, W. Díaz, A. 2003. Yacimientos metalíferos de la Carta Caldera, Región de Atacama. Servicio Nacional de Geología y Minería, Carta Geológica de Chile, Serie Recursos Minerales y Energéticos 22: 23 p., 1 mapa escala 1:100.000. Santiago.

Pizarro, B. 1943. Informe sobre Reservas de Minerales del Yacimiento Cobaltífero de la CIA. Minera Merceditas. Corporación de Fomento de la Producción Chile. 8 p.

Ruiz, C., Peebles, F. 1988. Geología y Yacimientos Metalíferos de Chile. Editorial Universitaria, 334 p.

Ruiz, C., Aguirre, L., Corvalan, J., Klohn, E. y Levi, B., 1965. Geología y Yacimientos Metalíferos de Chile. Instituto de Investigaciones Geológicas, Santiago. 302 pp.

SERNAGEOMIN, 2017. Propuesta para el estudio de yacimientos de cobalto y manganeso en las regiones de Atacama, Coquimbo y Metropolitana, Chile. Documento inédito, presentado a CORFO. 7 pp.

Thiele, R. 1980. Carta Geológica de Chile 1:250.000. Hoja Santiago, Región Metropolitana. Instituto de Investigaciones Geológicas, Carta Geológica de Chile, 39, 51.

Townley, B., Díaz, A., Luca, R., 2017. Estado del Arte y Potenciales Recursos Co y Mn en Chile. Informe CORFO, Diciembre 2017. 55 pp.

Townley, B., Díaz, A., Luca, R., 2017. Geología, alteración y mineralización preliminar de distritos / yacimientos seleccionados. Potenciales recursos de Cobalto y Manganeso en Chile: definici{on d zonas y selección de distritos / yacimientos u otras fuentes en Chile. Informe CORFO. Diciembre 2017. 29 pp.

Vasallo, L.F., 2008, Yacimientos Minerales Metálicos. 4ta Edición. Versión OnLine, Bol-e. Centro de Geociencias, UNAM Querétaro, México. 198 pp.

Villavicencio, E. 1946. Minas San Pablo 1 al 11, Cristo Rey 1 al 11 y Carbonillo 1 al 10, Sres. Eloy Pérez Araya y otros. (Inédito), Caja de Crédito Minero: 2 p.(*).

Vivallo, W.; Díaz, A.; Jorquera, R. 2008. Yacimientos Metalíferos de la Región de Atacama, Servicio Nacional de Geología y Minería, Carta Geológica de Chile, Serie Recursos Minerales y Energéticos, N° 27, 72 p., 1mapa escala 1: 500.000.

Welkner, D.; Arévalo, C.; Godoy, E. 2006. Geología de la Carta Freirina-El Morado, Región de Atacama. Servicio Nacional de Geología y Minería, Carta Geológica de Chile, Serie Geología Básica, No. 100, 50 p., 1 mapa escala 1:100.000.

www.hotchili.net.au/projects/productora/. Productora- Chile's next Coastal Copper Mine in the making. Hot Chile Limited. Página web. 2018.

Zamarsky, V., Conn, H., Tabak, M., 1973. Estudio geoquímico de los productos de interperismo de las rocas ultrabásicas (serpentinitas) en la Provincia de Valdivia, Chile. Revista Geológica de Chile, n.1, p. 81-102.

Zhang, W.; Cheng, C. Y. 2007. Manganese metallurgy review. Parte I: Leaching of ores/secondary materials and recovery of electrolytic/chemical manganese dioxide. Hydrometallurgy Vol. 89 pag. 137 – 159.

Appendix 1 Listing of studies and publications existing in digital format

- Carballo, A., 1979. Cobalto, níquel y zinc en piritas y calcopiritas de algunos yacimientos cupríferos en el norte de Chile. Actas Segundo Congreso Geológico de Chile. 18 pp.
- Lacassie, J.P.; Vivallo, W.; Díaz, A.; Ruiz del Solar, J., 2015. Geoquímica de yacimientos metálicos y de sedimentos, de las regiones de Atacama y Coquimbo, norte de Chile. Actas XIV Congreso Geológico de Chile. 4 pp.
- Lacassie, J.P.; Vivallo, W.; Díaz, A. 2016. Caracterización geoquímica de yacimientos metalíferos de la Región de Atacama mediante el uso de redes neuronales artificiales. Servicio Nacional de Geología y Minería, Informe Registrado IR-16-61: 177 p, 1 CD. Santiago.
- Mathur, R., Marschik, R., Ruiz, J., Munizaga, F., Leveille, R., Martin, W., 2002. Age of Mineralization of the Candelaria Fe Oxide Cu-Au Deposit and the Origin of the Chilean Iron Belt, Based on Re-Os Isotopes. Vol. 97, 2002, pp. 59–71.
- Pincheira, M., Rodriguez, M., Helle, S., Kelm, U., Frutos, J., 1997. El cobalto y níquel en sulfuros como indicadores de la fuente de los metales y ambientes de formación de depósitos. Actas VIII Congreso Geológico Chileno. 5 pp.
- Vasallo, L.F., 2008, Yacimientos Minerales Metálicos. 4ta Edición. Versión OnLine, Bol-e. Centro de Geociencias, UNAM Querétaro, México. 198 pp.
- Zamarsky, V., Conn, H., Tabak, M., 1973. Estudio geoquímico de los productos de interperismo de las rocas ultrabásicas (serpentinitas) en la Provincia de Valdivia, Chile. Revista Geológica de Chile, n.1, p. 81-102.

Appendix 2 Geochemical Analytical Results and analytical certificates

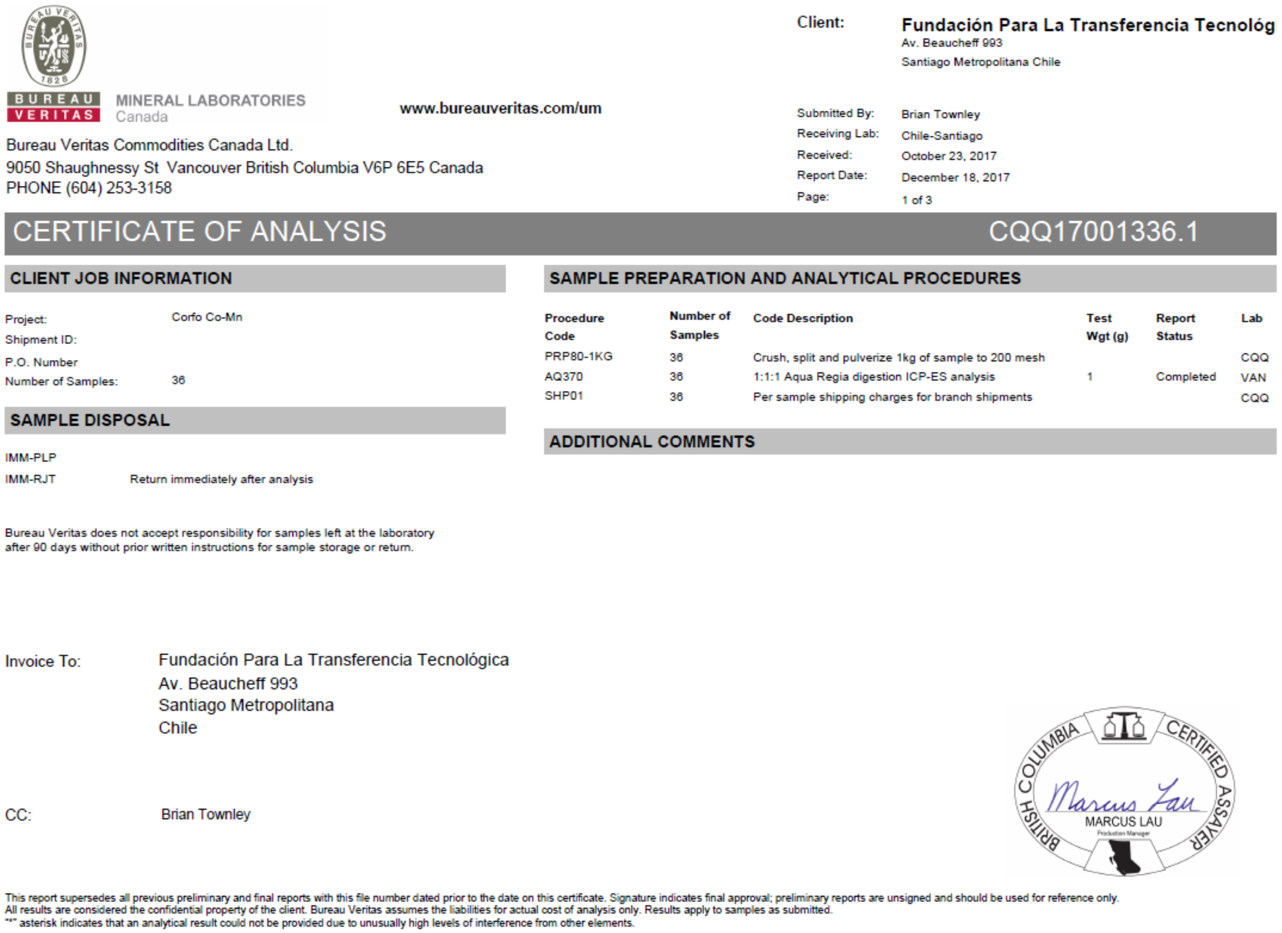
(Results and certificates in digital format in attached digital appendix)

						Method	WGHT	AQ370	AQ370	AQ370	AQ370	AQ370
						Analyte	Wgt	Mo	Cu	Pb	Zn	Ag
						Unit	KG	%	%	%	%	GM/T
						MDL	0,01	0,001	0,001	0,01	0,01	2
Sample	**Correlativo**	**UTMN(PSAD56)**	**UTME(PSAD56)**	**UTMN(WGS84)**	**UTME(WGS84)**	Type						
Mina Fresia 1_5	1	6820804	285033	6820469	284833	Rock	5,84	0,002	>10,000	<0,01	<0,01	10
Mina Despreciada	2	6822663	284946	6822328	284745	Rock	3,48	<0,001	0,054	<0,01	<0,01	<2
Las Marengo-1	3	6823182	285408	6822847	285207	Rock	3,09	<0,001	1,333	<0,01	<0,01	<2
Las Marengo-2	4	6823182	285408	6822847	285207	Rock	3,42	0,002	1,062	<0,01	<0,01	<2
Las Marengo-3	5	6824110	285453	6823774	285252	Rock	3,95	<0,001	2,967	<0,01	<0,01	6
Las Marengo-4	6	6824110	285453	6823774	285252	Rock	5,81	<0,001	0,683	<0,01	<0,01	<2
Las Marengo-5	7	6823143	286157	6822805	285959	Rock	3,16	<0,001	1,618	<0,01	<0,01	<2
Planta Relave-01	8	6823016	282368	6822680	282168	Rock	2,39	0,001	0,564	<0,01	<0,01	<2
Planta Relave-02	9	6823016	282368	6822680	282168	Rock	3,09	0,009	0,89	<0,01	<0,01	8
Planta Relave-03	10	6823016	282368	6822680	282168	Rock	5,09	0,002	3,765	<0,01	<0,01	5
Sector Labrar-01	11	6819943	282411	6819608	282211	Rock	4,75	0,003	2,136	<0,01	<0,01	<2
Sector Labrar-02	12	6820022	282513	6819687	282313	Rock	3,23	<0,001	2,379	<0,01	<0,01	3
Mina Delirio-01	13	6822117	285413	6821780	285150	Rock	3,94	<0,001	0,302	<0,01	<0,01	<2
Mina Delirio-02	14	6822117	285413	6821780	285150	Rock	3,37	<0,001	0,974	<0,01	<0,01	<2
Planta La Cobaltera-01	15	6823731	284340	6823394	284139	Rock	2,42	<0,001	1,223	<0,01	<0,01	2
Veta NN Qzo-01	16	6823681	285284	6823346	285083	Rock	3,44	<0,001	0,271	<0,01	<0,01	<2
Mina Blanca-01	17	6823493	285025	6823156	284824	Rock	4,02	<0,001	1,561	<0,01	0,01	6
Mina Blanca-02	18	6823493	285025	6823156	284824	Rock	3,55	<0,001	0,662	<0,01	<0,01	<2
Sector Paulita-01	19	6823643	286122	6823308	285922	Rock	4,46	<0,001	0,601	<0,01	<0,01	<2
Sector Los Morteros-01	20	6835577	337853	6837653	337653	Rock	3,36	<0,001	0,168	<0,01	<0,01	<2
Sector Los Morteros-02	21	6836217	336504	6835882	336302	Rock	3,66	<0,001	0,662	<0,01	<0,01	<2
CQ1	22	6652178	312902	6651846	312702	Rock	4,11	0,004	0,05	0,05	<0,01	<2
CQ2	23	6652178	312902	6651846	312702	Rock	2,35	0,007	0,069	0,06	<0,01	<2
CQ3	24	6652178	312902	6651846	312702	Rock	3,66	0,006	0,042	0,19	<0,01	<2
FR-01	25	6642369	308920	6642040	308720	Rock	3,37	<0,001	0,105	0,01	<0,01	<2
FR-02	26	6640827	309851	6640497	309651	Rock	4,38	0,002	0,058	<0,01	<0,01	3
Mi1	27	6652596	287951	6652264	287750	Rock	5,74	0,003	0,713	<0,01	<0,01	<2
Mi2	28	6652596	287951	6652264	287750	Rock	3,63	0,036	0,801	<0,01	<0,01	<2
Mi3	29	6652596	287951	6652264	287750	Rock	2,97	0,08	0,817	0,01	<0,01	<2
REL1	30	6657255	287090	6656926	286891	Rock	2,94	0,008	0,129	<0,01	<0,01	<2
TB-01	31	6658600	286505	6658269	286304	Rock	6	0,021	2,146	<0,01	<0,01	<2
MN-01	32	6658551	290387	6658218	290187	Rock	5,05	0,002	1,887	<0,01	<0,01	<2
MN-02	33	6657417	289724	6657085	289526	Rock	3,8	0,026	5,485	<0,01	<0,01	<2
MN-03	34	6657417	289724	6657085	289526	Rock	3,56	0,002	0,086	<0,01	<0,01	<2
MN-04	35	6657470	289952	6657140	289751	Rock	5,95	0,002	2,255	<0,01	<0,01	<2
LC-01	36	6685810	317570	6685478	317367	Rock	3,31	0,001	0,053	<0,01	<0,01	<2
BH20-793	37					Rock	3	<0,001	0,172	<0,01	<0,01	<2
BH20-489	38					Rock	3,54	<0,001	0,022	<0,01	<0,01	<2
BH11-902	39					Rock	2,4	<0,001	0,084	<0,01	<0,01	<2
BH21-1036,15	40					Rock	0,83	<0,001	0,082	<0,01	<0,01	<2
BH12-824	41					Rock	1,67	<0,001	0,048	<0,01	0,02	<2
BH15-685	42					Rock	2,23	<0,001	0,034	<0,01	<0,01	<2
MINA ESTRELLA 1	43					Rock	3,01	<0,001	2,323	<0,01	<0,01	5
MINA ESTRELLA 2	44					Rock	5,15	<0,001	0,683	<0,01	<0,01	<2
MINA ESTRELLA 3	45					Rock	2,82	<0,001	1,333	<0,01	0,01	3
MINA ESTRELLA 4	46					Rock	4,54	<0,001	5,241	<0,01	0,04	10
LEONA 5	47	6819043	323034	6818711	322833	Rock	4,16	0,002	0,32	<0,01	<0,01	<2
M-001	48	6257441	391499	6257122	391296	Rock	6,94	0,005	4,04	<0,01	<0,01	5
M-002	49	6257441	391499	6257122	391296	Rock	3,83	0,005	4,308	<0,01	<0,01	3
MAU-001	50					Rock	2,56	<0,001	0,028	<0,01	<0,01	<2

	AQ370	AQ370	AQ370	AQ370	AQ370	AQ370	AQ370	AQ370	AQ370	AQ370	AQ370	AQ370
	Ni	Co	Mn	Fe	As	Sr	Cd	Sb	Bi	Ca	P	Cr
	%	%	%	%	%	%	%	%	%	%	%	%
	0,001	0,001	0,01	0,01	0,01	0,001	0,001	0,001	0,01	0,01	0,001	0,001
Sample												
Mina Fresia 1_5	0,039	0,087	<0,01	31,54	0,08	0,006	<0,001	<0,001	<0,01	3,17	1,581	<0,001
Mina Despreciada	0,021	0,416	0,02	3,98	0,59	<0,001	<0,001	<0,001	<0,01	0,86	0,076	0,003
Las Marengo-1	0,011	0,278	0,01	6,7	0,71	0,019	<0,001	<0,001	<0,01	0,73	0,303	0,001
Las Marengo-2	0,016	0,049	<0,01	23,68	0,23	0,003	<0,001	<0,001	<0,01	0,04	0,068	<0,001
Las Marengo-3	0,023	0,079	0,06	10,25	0,1	0,002	<0,001	<0,001	<0,01	0,24	0,075	0,031
Las Marengo-4	0,028	0,443	0,03	3,5	0,77	0,012	<0,001	<0,001	<0,01	0,58	0,215	0,011
Las Marengo-5	0,013	0,017	0,03	6,17	0,12	<0,001	<0,001	<0,001	<0,01	0,06	0,122	<0,001
Planta Relave-01	0,006	0,011	0,06	9,21	0,02	0,003	<0,001	<0,001	<0,01	2,66	0,108	0,006
Planta Relave-02	0,002	0,012	0,01	22,51	0,01	0,005	<0,001	<0,001	<0,01	1,37	0,11	0,002
Planta Relave-03	0,037	0,189	0,13	10,14	0,29	0,004	<0,001	<0,001	<0,01	7,04	0,06	0,002
Sector Labrar-01	0,044	0,085	0,04	23,07	<0,01	0,001	<0,001	<0,001	<0,01	1,63	0,053	0,002
Sector Labrar-02	0,005	0,015	0,05	9,15	0,02	0,002	<0,001	<0,001	<0,01	3,21	0,061	0,002
Mina Delirio-01	0,12	0,781	0,03	1,84	1,19	0,001	<0,001	<0,001	<0,01	1,02	0,007	0,001
Mina Delirio-02	0,029	0,1	0,02	21,03	0,18	0,001	<0,001	<0,001	<0,01	0,13	0,067	0,003
Planta La Cobaltera-01	0,023	0,211	0,05	8,36	0,19	0,004	<0,001	0,002	<0,01	0,51	0,08	0,011
Veta NN Qzo-01	0,005	0,022	0,01	2,41	0,06	0,002	<0,001	<0,001	<0,01	0,18	0,073	0,002
Mina Blanca-01	0,045	0,649	0,01	4,9	1,07	0,002	<0,001	<0,001	<0,01	0,49	0,128	0,003
Mina Blanca-02	0,005	0,021	0,02	3,39	0,1	0,003	<0,001	<0,001	<0,01	0,11	0,039	0,001
Sector Paulita-01	0,007	0,005	0,01	3,74	0,02	0,003	<0,001	<0,001	<0,01	0,05	0,094	<0,001
Sector Los Morteros-01	0,002	0,002	0,07	11,99	<0,01	<0,001	<0,001	<0,001	<0,01	0,2	0,077	0,003
Sector Los Morteros-02	<0,001	<0,001	0,07	11,63	<0,01	<0,001	<0,001	<0,001	<0,01	0,21	0,041	<0,001
CQ1	<0,001	0,002	11,91	0,85	<0,01	0,053	<0,001	<0,001	<0,01	21,36	0,018	0,002
CQ2	0,001	0,002	>20,00	1,14	0,01	0,071	<0,001	<0,001	<0,01	13,2	0,027	0,003
CQ3	<0,001	0,001	>20,00	0,59	0,01	0,092	<0,001	<0,001	<0,01	17,26	0,012	0,003
FR-01	0,001	0,002	17,05	0,37	0,04	0,039	<0,001	<0,001	<0,01	25,71	0,006	0,003
FR-02	0,002	0,002	>20,00	1,22	0,04	0,027	<0,001	<0,001	<0,01	10,79	0,023	0,004
Mi1	0,012	0,483	0,3	5,92	0,64	0,003	<0,001	<0,001	<0,01	1,37	0,105	0,006
Mi2	0,017	>1,000	0,6	2,44	1,76	0,004	<0,001	0,003	<0,01	16,62	0,748	0,003
Mi3	0,063	>1,000	0,17	4,27	9,31	0,002	<0,001	0,01	<0,01	1,54	0,478	0,003
REL1	0,007	0,018	0,17	15,85	<0,01	0,009	<0,001	<0,001	<0,01	7,03	2,346	<0,001
TB-01	0,005	0,027	0,07	22,14	0,04	0,002	<0,001	0,001	<0,01	2,44	0,676	0,001
MN-01	0,007	0,005	0,06	>40,00	<0,01	0,005	<0,001	<0,001	<0,01	6,75	2,436	<0,001
MN-02	<0,001	0,002	0,13	10,23	<0,01	0,017	<0,001	<0,001	<0,01	15,08	2,903	<0,001
MN-03	0,002	0,003	0,12	10,57	<0,01	0,01	<0,001	<0,001	<0,01	2,23	0,117	<0,001
MN-04	0,017	0,028	0,07	>40,00	<0,01	0,005	<0,001	<0,001	<0,01	4,59	0,864	<0,001
LC-01	0,002	0,003	>20,00	2,16	0,04	0,036	<0,001	<0,001	<0,01	4,87	0,035	0,004
BH20-793	0,005	0,01	0,17	39,28	<0,01	<0,001	<0,001	<0,001	<0,01	0,68	0,052	0,001
BH20-489	0,005	0,009	0,18	19,82	<0,01	0,005	<0,001	<0,001	<0,01	11,48	4,931	0,001
BH11-902	0,032	0,027	0,2	26,72	<0,01	0,002	<0,001	<0,001	<0,01	1,41	0,455	<0,001
BH21-1036,15	0,018	0,013	0,25	17,11	<0,01	0,002	<0,001	<0,001	<0,01	0,91	0,22	0,001
BH12-824	0,008	0,012	0,16	31,96	<0,01	0,003	<0,001	<0,001	<0,01	2,13	0,697	0,002
BH15-685	0,003	0,003	0,13	>40,00	<0,01	<0,001	<0,001	<0,001	<0,01	3,69	0,225	0,001
MINA ESTRELLA 1	0,917	0,199	0,08	36,71	0,01	<0,001	<0,001	<0,001	<0,01	3,29	1,441	<0,001
MINA ESTRELLA 2	0,191	0,104	0,06	>40,00	<0,01	<0,001	<0,001	<0,001	<0,01	1,96	0,757	<0,001
MINA ESTRELLA 3	0,285	0,251	0,04	>40,00	<0,01	<0,001	<0,001	<0,001	<0,01	3	1,286	<0,001
MINA ESTRELLA 4	0,43	0,141	0,04	>40,00	<0,01	<0,001	<0,001	<0,001	<0,01	3,56	1,584	<0,001
LEONA 5	0,076	0,074	0,16	39,3	<0,01	0,001	<0,001	<0,001	<0,01	2,51	0,344	0,001
M-001	0,003	0,007	0,51	>40,00	<0,01	<0,001	<0,001	<0,001	<0,01	0,35	0,028	<0,001
M-002	0,001	0,17	1,19	19,78	0,21	0,002	<0,001	<0,001	<0,01	0,44	0,029	<0,001
MAU-001	0,009	0,02	0,07	31,11	0,01	0,002	<0,001	<0,001	<0,01	1,73	0,031	0,002

	AQ370	AQ370	AQ370	AQ370	AQ370	AQ370	AQ370		
	Mg	Al	Na	K	W	Hg	S		
	%	%	%	%	%	%	%		
	0,01	0,01	0,01	0,01	0,001	0,001	0,05		
Sample								**DISTRITO**	**MINA**
Mina Fresia 1_5	0,19	0,31	0,02	0,03	<0,001	<0,001	1,02	SAN JUAN	FRESIA
Mina Despreciada	1,23	2,14	0,03	0,29	<0,001	<0,001	0,26		DESPRECIADA
Las Marengo-1	0,12	0,74	0,03	0,12	<0,001	<0,001	0,05		MARENGO
Las Marengo-2	0,03	0,5	0,01	0,19	<0,001	<0,001	0,06		MARENGO
Las Marengo-3	2,6	2,68	0,03	0,03	<0,001	<0,001	<0,05		LAS MARENGO
Las Marengo-4	1,31	1,47	0,03	0,05	<0,001	<0,001	<0,05		LAS MARENGO
Las Marengo-5	0,11	0,4	0,01	0,22	<0,001	<0,001	<0,05		LAS MARENGO-5
Planta Relave-01	2	3,25	0,05	0,64	<0,001	<0,001	0,79		PLANTA QUEBRADITA
Planta Relave-02	0,3	0,83	0,03	0,09	<0,001	<0,001	11,59		PLANTA QUEBRADITA
Planta Relave-03	1,9	1,55	0,01	0,12	<0,001	<0,001	5,86		PLANTA QUEBRADITA
Sector Labrar-01	1,36	3,11	0,01	1,91	<0,001	<0,001	16,36		SECTOR LABRAR
Sector Labrar-02	0,93	1,96	0,03	0,46	<0,001	<0,001	3,41		SECTOR LABRAR
Mina Delirio-01	0,24	0,26	0,01	<0,01	<0,001	<0,001	0,26		DELIRIO
Mina Delirio-02	1,28	2,04	0,03	0,05	<0,001	<0,001	<0,05		DELIRIO
Planta La Cobaltera-01	1,6	2,28	0,04	0,24	<0,001	<0,001	1,19		PLANTA LA COBALTERA
Veta NN Qzo-01	0,7	0,97	0,06	0,07	<0,001	<0,001	<0,05		NN
Mina Blanca-01	0,12	0,18	0,01	<0,01	<0,001	<0,001	0,82		BLANCA
Mina Blanca-02	1,14	1,53	0,03	0,03	<0,001	<0,001	<0,05		BLANCA
Sector Paulita-01	1,42	1,23	0,02	<0,01	<0,001	<0,001	<0,05		Camino Mina Paulita
Sector Los Morteros-01	2,79	3,57	0,06	2,07	<0,001	<0,001	0,75	LOS MORTEROS	
Sector Los Morteros-02	1,58	1,79	<0,01	<0,01	0,006	<0,001	<0,05	LOS MORTEROS	
CQ1	0,09	0,3	0,06	0,09	<0,001	<0,001	0,23	CORRAL QUEMADO	CORRAL QUEMADO
CQ2	0,16	0,52	0,05	0,15	<0,001	<0,001	0,22		CORRAL QUEMADO
CQ3	0,09	0,46	0,03	0,17	<0,001	<0,001	0,14		CORRAL QUEMADO
FR-01	0,27	0,33	0,02	0,03	<0,001	<0,001	0,13	FRAGUA	
FR-02	0,39	0,5	0,03	0,07	<0,001	<0,001	0,24		
Mi1	2,05	2,3	0,04	0,08	<0,001	<0,001	0,93	TAMBILLOS	MINILLAS
Mi2	0,8	0,86	0,01	0,11	<0,001	<0,001	1,51		MINILLAS
Mi3	0,74	0,96	0,02	0,09	<0,001	<0,001	4,63		MINILLAS
REL1	3,09	2,67	0,24	0,08	<0,001	<0,001	0,27		PLANTA ABANDONADA
TB-01	1,77	1,54	0,03	0,05	<0,001	<0,001	2,13		
MN-01	1,16	0,63	0,03	0,01	<0,001	<0,001	1,79		MANZANO 1 Ó 2
MN-02	1,64	1,83	<0,01	0,06	<0,001	<0,001	4,18		
MN-03	2,89	2,83	0,05	0,03	<0,001	<0,001	0,07		
MN-04	0,16	0,18	0,02	<0,01	<0,001	<0,001	3,12		
LC-01	0,31	1,88	0,05	0,05	<0,001	<0,001	0,19	LAS CAÑAS	
BH20-793	2,28	1,67	0,03	0,09	<0,001	<0,001	0,82		
BH20-489	3,54	2,19	0,1	0,05	<0,001	<0,001	0,42		
BH11-902	3,24	2,9	0,17	0,22	<0,001	<0,001	2,99		
BH21-1036,15	3,08	2,89	0,22	0,16	<0,001	<0,001	2,25		
BH12-824	1,5	1,79	0,21	0,38	<0,001	<0,001	1,65		
BH15-685	0,77	0,22	<0,01	0,02	<0,001	<0,001	0,11		
MINA ESTRELLA 1	0,67	0,35	<0,01	<0,01	<0,001	<0,001	>30,00	Productora	Estrella
MINA ESTRELLA 2	1,36	0,67	<0,01	0,11	<0,001	<0,001	13,1	Productora	Estrella
MINA ESTRELLA 3	0,34	0,14	<0,01	0,01	<0,001	<0,001	25,01	Productora	Estrella
MINA ESTRELLA 4	0,31	0,14	<0,01	0,01	<0,001	<0,001	24,43	Productora	Estrella
LEONA 5	0,62	0,47	<0,01	<0,01	<0,001	<0,001	9,04	Productora	Leona
M-001	0,09	0,11	0,02	0,04	0,039	<0,001	4,15		Mercedita
M-002	0,5	0,35	0,01	0,1	0,02	<0,001	4,22		Mercedita
MAU-001	0,35	0,26	0,08	<0,01	0,004	<0,001	>30,00		

Sample	**DESCRIPCIÓN**
Mina Fresia 1_5	Desmontes de vetas de Mgt(Mar)-Qzo-Turm-Cpy-Arspy-Bor-Alm-Atab-Cup-Cris-Atac-Antl
Mina Despreciada	Desmontes con Eritrina asociada a Qzo-Turm (Cal)
Las Marengo-1	Vetas de Qzo-Lim-Jar
Las Marengo-2	Vetas Ox.Cu-Eri-Arc-Qzo-Ox.Fe
Las Marengo-3	Vetas de Qzo-Turm-Ox.Cu-Ox.Mn-Lim-Jar
Las Marengo-4	Vetas de Qzo-Turm-Eri-Cpy-Py
Las Marengo-5	
Planta Relave-01	Relave
Planta Relave-02	Piritas oxidadas
Planta Relave-03	Vetas de Qzo-Cal-Ser-Clo-Ox.Fe-(OxCu) en intrusivo y esquistos de alimentador planta
Sector Labrar-01	Vetas de Mgt-Qzo(Cal)-Py(Arspy)-Cpy-Clo-Bt
Sector Labrar-02	Vetas de Mgt-Qzo(Cal)-Py(Arspy)-Cpy-Clo-Bt
Mina Delirio-01	Vetas Qzo-Turm-Eri-Cpy-Py
Mina Delirio-02	Brecha matriz de Ox.Mn
Planta La Cobaltera-01	Ripios
Veta NN Qzo-01	Veta Qzo-Lim-Jar-(Ox.Cu-Ox.Mn)
Mina Blanca-01	Veta Qzo-Turm-Py-Eri
Mina Blanca-02	Esquistos con sulfuros diseminados y escasos minerales Ox.Cu
Sector Paulita-01	Veta Qzo-Turm-Eri-(Ox.Cu)
Sector Los Morteros-01	Andesita porfídica con Mgt-Act(Clo) diseminada/pervasiva y Py-Cpy-Po, diseminada y en vetillas
Sector Los Morteros-02	Estructura (Pique) con Hmt, Mgt, Qzo, Óxidos de Cu.
CQ1	Granza(gravilla) del descarte de proceso separación de Ox.Mn
CQ2	Material fino del descarte de proceso separación de Ox.Mn
CQ3	Mantos de Ox.Mn (Masivo-Escoreáceo-bandeado-clástico)
FR-01	Mantos de Ox.Mn en secuencia de areniscas volcánicas rojas
FR-02	Mantos de Ox.Mn en secuencia de areniscas volcánicas rojas
Mi1	Rocas volcánicas y volcanosedimentarias anfibolitizadas con Py-(Cpy-Arspy)
Mi2	Vetas Cal-Py-(Cpy-Mo)
Mi3	Rocas volcanoclásticas con Cob-Eri
REL1	Relave con abundante Mgt
TB-01	Desmonte con vetas de Mgt-(Cal)-Cpy-Py-Anf-Epdt-Eri
MN-01	Vetas de Mgt-(Cal)-Cpy-Py-Anf-Ap-Epdt en intrusivo
MN-02	Vetas de Mgt-(Cal)-Cpy-Py-Anf-Ap-Epdt en metandesita
MN-03	diseminado de Mgt-(Cal)-Cpy-Py-Anf-Ap-Epdt en metandesita
MN-04	Vetas de Mgt-(Cal)-Cpy-Py-Anf-Ap-Epdt en intrusivo y metandesita
LC-01	Mantos centimétricos a métricos intercalados con areniscas y fangolitas rojas
BH20-793	
BH20-489	
BH11-902	
BH21-1036,15	Sondaje BH21 BOX 80. Muestra tramos 1028,081 - 1031; 1031,0 - 1036,5; 1036,15 - 1041,46 pies
BH12-824	Sondaje BH12 BOX 53. Muestra tramos 820 - 824; 824 - 826 pies
BH15-685	Sondaje BH15 BOX 52.
MINA ESTRELLA 1	Manto 30 - 40 cm interior mina.
MINA ESTRELLA 2	Frente Parte superio, menor cantidad de sulfuros
MINA ESTRELLA 3	Frente Parte inferior mayor cantidad de sulfuros
MINA ESTRELLA 4	Desmonte fuera de mina
LEONA 5	Desmonte fuera de mina - pique donde sacaban oro
M-001	Zona planta, mineralización sulfuros y óxidos de cobre, Pirita, Hemtita, Hematita especula, alteración cuarzo, turmalina. Hidróxidos de Hierro,
M-002	Zona planta, mineralización sulfuros y óxidos de cobre, Pirita, Hemtita, Hematita especula, alteración cuarzo, turmalina. Hidróxidos de Hierro,
MAU-001	



Client: **Fundación Para La Transferencia Tecnológ**
Av. Beaucheff 993
Santiago Metropolitana Chile

BUREAU VERITAS MINERAL LABORATORIES Canada

www.bureauveritas.com/um

Bureau Veritas Commodities Canada Ltd.
9050 Shaughnessy St Vancouver British Columbia V6P 6E5 Canada
PHONE (604) 253-3158

Submitted By:	Brian Townley
Receiving Lab:	Chile-Santiago
Received:	October 23, 2017
Report Date:	December 18, 2017
Page:	1 of 3

CERTIFICATE OF ANALYSIS CQQ17001336.1

CLIENT JOB INFORMATION

Project:	Corfo Co-Mn
Shipment ID:	
P.O. Number	
Number of Samples:	36

SAMPLE DISPOSAL

IMM-PLP	
IMM-RJT	Return immediately after analysis

Bureau Veritas does not accept responsibility for samples left at the laboratory after 90 days without prior written instructions for sample storage or return.

SAMPLE PREPARATION AND ANALYTICAL PROCEDURES

Procedure Code	Number of Samples	Code Description	Test Wgt (g)	Report Status	Lab
PRP80-1KG	36	Crush, split and pulverize 1kg of sample to 200 mesh			CQQ
AQ370	36	1:1:1 Aqua Regia digestion ICP-ES analysis	1	Completed	VAN
SHP01	36	Per sample shipping charges for branch shipments			CQQ

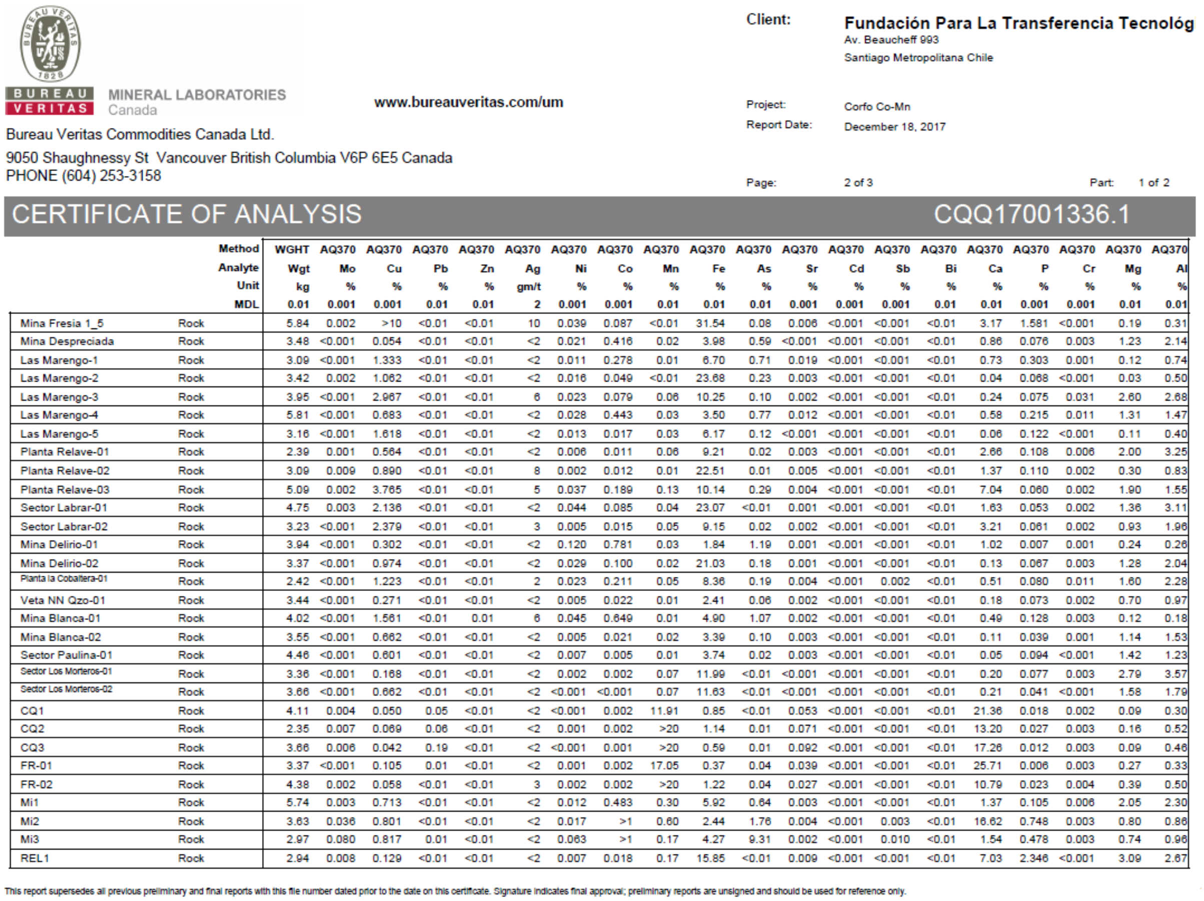
ADDITIONAL COMMENTS

Invoice To: Fundación Para La Transferencia Tecnológica
Av. Beaucheff 993
Santiago Metropolitana
Chile

CC: Brian Townley

Marcus Lau
MARCUS LAU

This report supersedes all previous preliminary and final reports with this file number dated prior to the date on this certificate. Signature indicates final approval; preliminary reports are unsigned and should be used for reference only.
All results are considered the confidential property of the client. Bureau Veritas assumes the liabilities for actual cost of analysis only. Results apply to samples as submitted.
"*" asterisk indicates that an analytical result could not be provided due to unusually high levels of interference from other elements.



BUREAU VERITAS
MINERAL LABORATORIES
Canada

www.bureauveritas.com/um

Bureau Veritas Commodities Canada Ltd.
9050 Shaughnessy St Vancouver British Columbia V6P 6E5 Canada
PHONE (604) 253-3158

Client: **Fundación Para La Transferencia Tecnológ**
Av. Beaucheff 993
Santiago Metropolitana Chile

Project: Corfo Co-Mn
Report Date: December 18, 2017

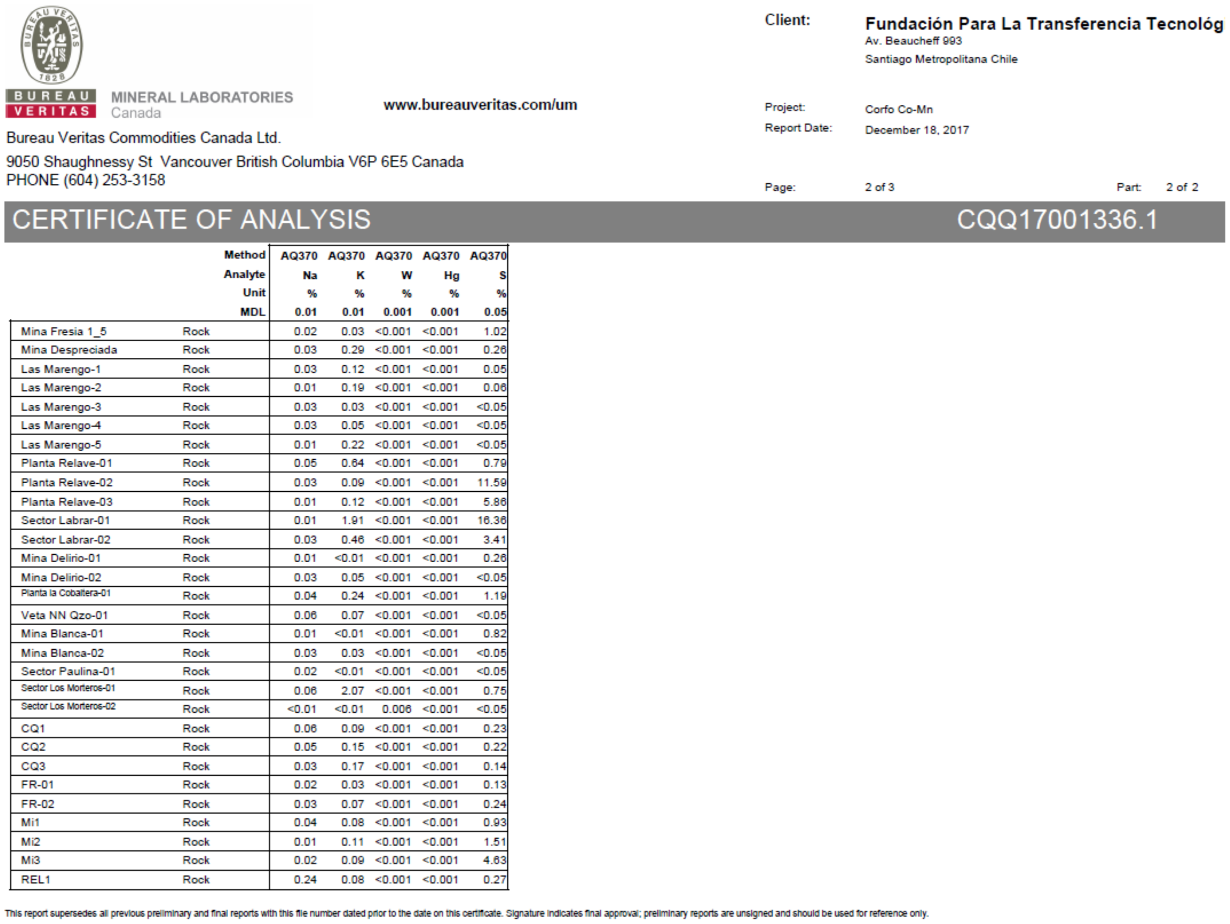
Page: 2 of 3
Part: 1 of 2

CERTIFICATE OF ANALYSIS

CQQ17001336.1

	Method	**WGHT**	**AQ370**	**AQ370**	**AQ370**	**AQ370**	**AQ370**	**AQ370**	**AQ370**	**AQ370**	**AQ370**	**AQ370**	**AQ370**	**AQ370**	**AQ370**	**AQ370**	**AQ370**	**AQ370**	**AQ370**	**AQ370**	**AQ370**
	Analyte	**Wgt**	**Mo**	**Cu**	**Pb**	**Zn**	**Ag**	**Ni**	**Co**	**Mn**	**Fe**	**As**	**Sr**	**Cd**	**Sb**	**Bi**	**Ca**	**P**	**Cr**	**Mg**	**Al**
	Unit	**kg**	**%**	**%**	**%**	**%**	**gm/t**	**%**	**%**	**%**	**%**	**%**	**%**	**%**	**%**	**%**	**%**	**%**	**%**	**%**	**%**
	MDL	**0.01**	**0.001**	**0.001**	**0.01**	**0.01**	**2**	**0.001**	**0.001**	**0.01**	**0.01**	**0.01**	**0.001**	**0.001**	**0.001**	**0.01**	**0.01**	**0.001**	**0.001**	**0.01**	**0.01**
Mina Fresia 1_5	Rock	5.84	0.002	>10	<0.01	<0.01	10	0.039	0.087	<0.01	31.54	0.08	0.006	<0.001	<0.001	<0.01	3.17	1.581	<0.001	0.19	0.31
Mina Despreciada	Rock	3.48	<0.001	0.054	<0.01	<0.01	<2	0.021	0.416	0.02	3.98	0.59	<0.001	<0.001	<0.001	<0.01	0.86	0.076	0.003	1.23	2.14
Las Marengo-1	Rock	3.09	<0.001	1.333	<0.01	<0.01	<2	0.011	0.278	0.01	6.70	0.71	0.019	<0.001	<0.001	<0.01	0.73	0.303	0.001	0.12	0.74
Las Marengo-2	Rock	3.42	0.002	1.062	<0.01	<0.01	<2	0.016	0.049	<0.01	23.68	0.23	0.003	<0.001	<0.001	<0.01	0.04	0.068	<0.001	0.03	0.50
Las Marengo-3	Rock	3.95	<0.001	2.967	<0.01	<0.01	6	0.023	0.079	0.06	10.25	0.10	0.002	<0.001	<0.001	<0.01	0.24	0.075	0.031	2.60	2.68
Las Marengo-4	Rock	5.81	<0.001	0.683	<0.01	<0.01	<2	0.028	0.443	0.03	3.50	0.77	0.012	<0.001	<0.001	<0.01	0.58	0.215	0.011	1.31	1.47
Las Marengo-5	Rock	3.16	<0.001	1.618	<0.01	<0.01	<2	0.013	0.017	0.03	6.17	0.12	<0.001	<0.001	<0.001	<0.01	0.06	0.122	<0.001	0.11	0.40
Planta Relave-01	Rock	2.39	0.001	0.564	<0.01	<0.01	<2	0.006	0.011	0.06	9.21	0.02	0.003	<0.001	<0.001	<0.01	2.66	0.108	0.006	2.00	3.25
Planta Relave-02	Rock	3.09	0.009	0.890	<0.01	<0.01	8	0.002	0.012	0.01	22.51	0.01	0.005	<0.001	<0.001	<0.01	1.37	0.110	0.002	0.30	0.83
Planta Relave-03	Rock	5.09	0.002	3.765	<0.01	<0.01	5	0.037	0.189	0.13	10.14	0.29	0.004	<0.001	<0.001	<0.01	7.04	0.060	0.002	1.90	1.55
Sector Labrar-01	Rock	4.75	0.003	2.136	<0.01	<0.01	<2	0.044	0.085	0.04	23.07	<0.01	0.001	<0.001	<0.001	<0.01	1.63	0.053	0.002	1.36	3.11
Sector Labrar-02	Rock	3.23	<0.001	2.379	<0.01	<0.01	3	0.005	0.015	0.05	9.15	0.02	0.002	<0.001	<0.001	<0.01	3.21	0.061	0.002	0.93	1.96
Mina Delirio-01	Rock	3.94	<0.001	0.302	<0.01	<0.01	<2	0.120	0.781	0.03	1.84	1.19	0.001	<0.001	<0.001	<0.01	1.02	0.007	0.001	0.24	0.26
Mina Delirio-02	Rock	3.37	<0.001	0.974	<0.01	<0.01	<2	0.029	0.100	0.02	21.03	0.18	0.001	<0.001	<0.001	<0.01	0.13	0.067	0.003	1.28	2.04
Planta la Cobaltera-01	Rock	2.42	<0.001	1.223	<0.01	<0.01	2	0.023	0.211	0.05	8.36	0.19	0.004	<0.001	0.002	<0.01	0.51	0.080	0.011	1.60	2.28
Veta NN Qzo-01	Rock	3.44	<0.001	0.271	<0.01	<0.01	<2	0.005	0.022	0.01	2.41	0.06	0.002	<0.001	<0.001	<0.01	0.18	0.073	0.002	0.70	0.97
Mina Blanca-01	Rock	4.02	<0.001	1.561	<0.01	0.01	6	0.045	0.649	0.01	4.90	1.07	0.002	<0.001	<0.001	<0.01	0.49	0.128	0.003	0.12	0.18
Mina Blanca-02	Rock	3.55	<0.001	0.662	<0.01	<0.01	<2	0.005	0.021	0.02	3.39	0.10	0.003	<0.001	<0.001	<0.01	0.11	0.039	0.001	1.14	1.53
Sector Paulina-01	Rock	4.46	<0.001	0.601	<0.01	<0.01	<2	0.007	0.005	0.01	3.74	0.02	0.003	<0.001	<0.001	<0.01	0.05	0.094	<0.001	1.42	1.23
Sector Los Morteros-01	Rock	3.36	<0.001	0.168	<0.01	<0.01	<2	0.002	0.002	0.07	11.99	<0.01	<0.001	<0.001	<0.001	<0.01	0.20	0.077	0.003	2.79	3.57
Sector Los Morteros-02	Rock	3.66	<0.001	0.662	<0.01	<0.01	<2	<0.001	<0.001	0.07	11.63	<0.01	<0.001	<0.001	<0.001	<0.01	0.21	0.041	<0.001	1.58	1.79
CQ1	Rock	4.11	0.004	0.050	0.05	<0.01	<2	<0.001	0.002	11.91	0.85	<0.01	0.053	<0.001	<0.001	<0.01	21.36	0.018	0.002	0.09	0.30
CQ2	Rock	2.35	0.007	0.069	0.06	<0.01	<2	0.001	0.002	>20	1.14	0.01	0.071	<0.001	<0.001	<0.01	13.20	0.027	0.003	0.16	0.52
CQ3	Rock	3.66	0.006	0.042	0.19	<0.01	<2	<0.001	0.001	>20	0.59	0.01	0.092	<0.001	<0.001	<0.01	17.26	0.012	0.003	0.09	0.46
FR-01	Rock	3.37	<0.001	0.105	0.01	<0.01	<2	0.001	0.002	17.05	0.37	0.04	0.039	<0.001	<0.001	<0.01	25.71	0.006	0.003	0.27	0.33
FR-02	Rock	4.38	0.002	0.058	<0.01	<0.01	3	0.002	0.002	>20	1.22	0.04	0.027	<0.001	<0.001	<0.01	10.79	0.023	0.004	0.39	0.50
Mi1	Rock	5.74	0.003	0.713	<0.01	<0.01	<2	0.012	0.483	0.30	5.92	0.64	0.003	<0.001	<0.001	<0.01	1.37	0.105	0.006	2.05	2.30
Mi2	Rock	3.63	0.036	0.801	<0.01	<0.01	<2	0.017	>1	0.60	2.44	1.76	0.004	<0.001	0.003	<0.01	16.62	0.748	0.003	0.80	0.86
Mi3	Rock	2.97	0.080	0.817	0.01	<0.01	<2	0.063	>1	0.17	4.27	9.31	0.002	<0.001	0.010	<0.01	1.54	0.478	0.003	0.74	0.96
REL1	Rock	2.94	0.008	0.129	<0.01	<0.01	<2	0.007	0.018	0.17	15.85	<0.01	0.009	<0.001	<0.001	<0.01	7.03	2.346	<0.001	3.09	2.67

This report supersedes all previous preliminary and final reports with this file number dated prior to the date on this certificate. Signature indicates final approval; preliminary reports are unsigned and should be used for reference only.



BUREAU VERITAS MINERAL LABORATORIES Canada

www.bureauveritas.com/um

Bureau Veritas Commodities Canada Ltd.

9050 Shaughnessy St Vancouver British Columbia V6P 6E5 Canada
PHONE (604) 253-3158

Client: **Fundación Para La Transferencia Tecnológ**
Av. Beaucheff 993
Santiago Metropolitana Chile

Project: Corfo Co-Mn
Report Date: December 18, 2017

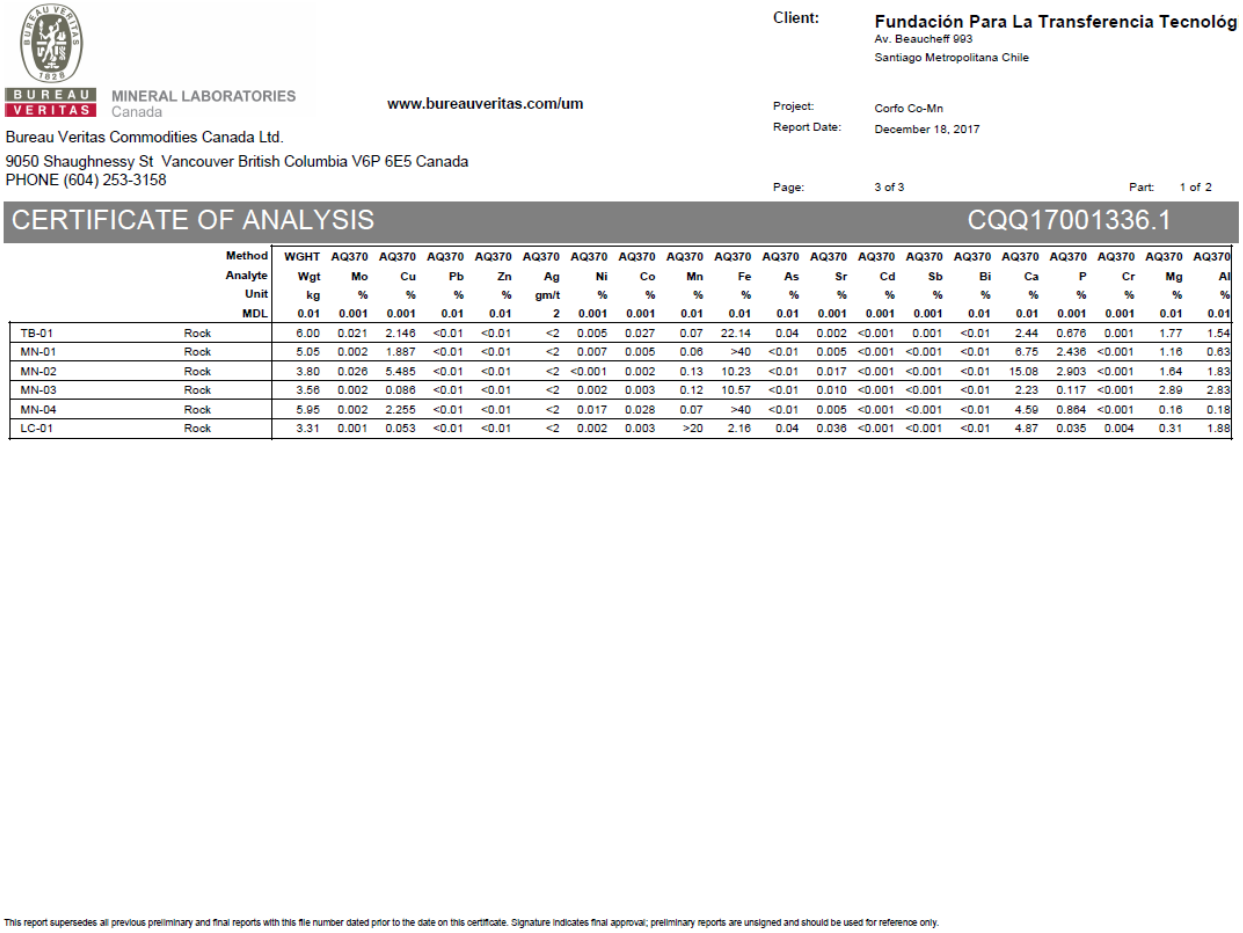
Page: 2 of 3 Part: 2 of 2

CERTIFICATE OF ANALYSIS

CQQ17001336.1

	Method	**AQ370**	**AQ370**	**AQ370**	**AQ370**	**AQ370**
	Analyte	**Na**	**K**	**W**	**Hg**	**S**
	Unit	**%**	**%**	**%**	**%**	**%**
	MDL	**0.01**	**0.01**	**0.001**	**0.001**	**0.05**
Mina Fresia 1_5	Rock	0.02	0.03	<0.001	<0.001	1.02
Mina Despreciada	Rock	0.03	0.29	<0.001	<0.001	0.26
Las Marengo-1	Rock	0.03	0.12	<0.001	<0.001	0.05
Las Marengo-2	Rock	0.01	0.19	<0.001	<0.001	0.06
Las Marengo-3	Rock	0.03	0.03	<0.001	<0.001	<0.05
Las Marengo-4	Rock	0.03	0.05	<0.001	<0.001	<0.05
Las Marengo-5	Rock	0.01	0.22	<0.001	<0.001	<0.05
Planta Relave-01	Rock	0.05	0.64	<0.001	<0.001	0.79
Planta Relave-02	Rock	0.03	0.09	<0.001	<0.001	11.59
Planta Relave-03	Rock	0.01	0.12	<0.001	<0.001	5.86
Sector Labrar-01	Rock	0.01	1.91	<0.001	<0.001	16.36
Sector Labrar-02	Rock	0.03	0.46	<0.001	<0.001	3.41
Mina Delirio-01	Rock	0.01	<0.01	<0.001	<0.001	0.26
Mina Delirio-02	Rock	0.03	0.05	<0.001	<0.001	<0.05
Planta la Cobaltera-01	Rock	0.04	0.24	<0.001	<0.001	1.19
Veta NN Qzo-01	Rock	0.06	0.07	<0.001	<0.001	<0.05
Mina Blanca-01	Rock	0.01	<0.01	<0.001	<0.001	0.82
Mina Blanca-02	Rock	0.03	0.03	<0.001	<0.001	<0.05
Sector Paulina-01	Rock	0.02	<0.01	<0.001	<0.001	<0.05
Sector Los Morteros-01	Rock	0.06	2.07	<0.001	<0.001	0.75
Sector Los Morteros-02	Rock	<0.01	<0.01	0.006	<0.001	<0.05
CQ1	Rock	0.06	0.09	<0.001	<0.001	0.23
CQ2	Rock	0.05	0.15	<0.001	<0.001	0.22
CQ3	Rock	0.03	0.17	<0.001	<0.001	0.14
FR-01	Rock	0.02	0.03	<0.001	<0.001	0.13
FR-02	Rock	0.03	0.07	<0.001	<0.001	0.24
Mi1	Rock	0.04	0.08	<0.001	<0.001	0.93
Mi2	Rock	0.01	0.11	<0.001	<0.001	1.51
Mi3	Rock	0.02	0.09	<0.001	<0.001	4.63
REL1	Rock	0.24	0.08	<0.001	<0.001	0.27

This report supersedes all previous preliminary and final reports with this file number dated prior to the date on this certificate. Signature indicates final approval; preliminary reports are unsigned and should be used for reference only.



BUREAU VERITAS MINERAL LABORATORIES Canada

www.bureauveritas.com/um

Bureau Veritas Commodities Canada Ltd.

9050 Shaughnessy St Vancouver British Columbia V6P 6E5 Canada
PHONE (604) 253-3158

Client: **Fundación Para La Transferencia Tecnológ**
Av. Beaucheff 993
Santiago Metropolitana Chile

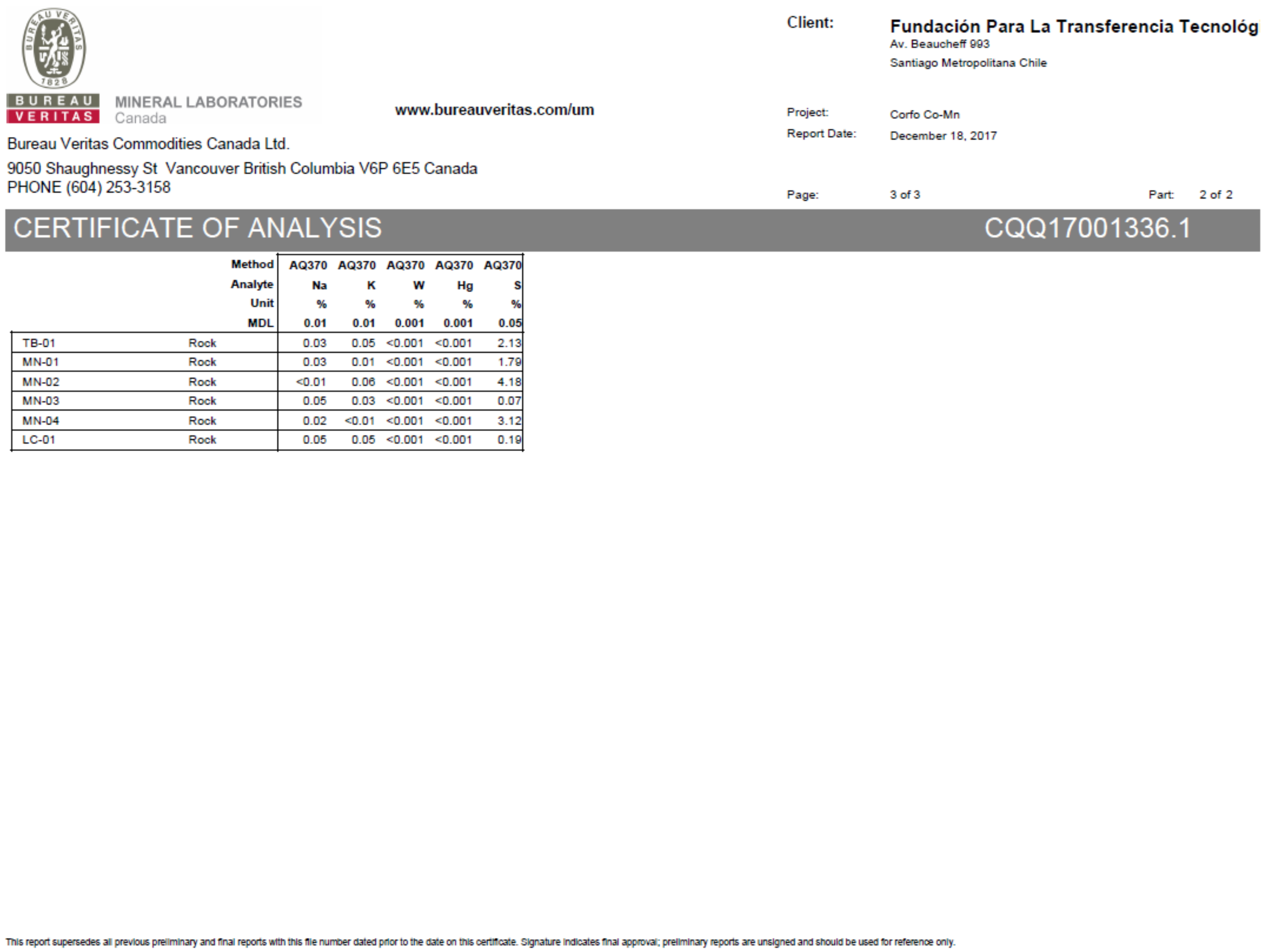
Project: Corfo Co-Mn
Report Date: December 18, 2017

Page: 3 of 3
Part: 1 of 2

CERTIFICATE OF ANALYSIS

CQQ17001336.1

	Method	**WGHT**	**AQ370**	**AQ370**	**AQ370**	**AQ370**	**AQ370**	**AQ370**	**AQ370**	**AQ370**	**AQ370**	**AQ370**	**AQ370**	**AQ370**	**AQ370**	**AQ370**	**AQ370**	**AQ370**	**AQ370**	**AQ370**	**AQ370**
	Analyte	**Wgt**	**Mo**	**Cu**	**Pb**	**Zn**	**Ag**	**Ni**	**Co**	**Mn**	**Fe**	**As**	**Sr**	**Cd**	**Sb**	**Bi**	**Ca**	**P**	**Cr**	**Mg**	**Al**
	Unit	**kg**	**%**	**%**	**%**	**%**	**gm/t**	**%**	**%**	**%**	**%**	**%**	**%**	**%**	**%**	**%**	**%**	**%**	**%**	**%**	**%**
	MDL	**0.01**	**0.001**	**0.001**	**0.01**	**0.01**	**2**	**0.001**	**0.001**	**0.01**	**0.01**	**0.01**	**0.001**	**0.001**	**0.001**	**0.01**	**0.01**	**0.001**	**0.001**	**0.01**	**0.01**
TB-01	Rock	6.00	0.021	2.146	<0.01	<0.01	<2	0.005	0.027	0.07	22.14	0.04	0.002	<0.001	0.001	<0.01	2.44	0.676	0.001	1.77	1.54
MN-01	Rock	5.05	0.002	1.887	<0.01	<0.01	<2	0.007	0.005	0.06	>40	<0.01	0.005	<0.001	<0.001	<0.01	6.75	2.436	<0.001	1.16	0.63
MN-02	Rock	3.80	0.026	5.485	<0.01	<0.01	<2	<0.001	0.002	0.13	10.23	<0.01	0.017	<0.001	<0.001	<0.01	15.08	2.903	<0.001	1.64	1.83
MN-03	Rock	3.56	0.002	0.086	<0.01	<0.01	<2	0.002	0.003	0.12	10.57	<0.01	0.010	<0.001	<0.001	<0.01	2.23	0.117	<0.001	2.89	2.83
MN-04	Rock	5.95	0.002	2.255	<0.01	<0.01	<2	0.017	0.028	0.07	>40	<0.01	0.005	<0.001	<0.001	<0.01	4.59	0.864	<0.001	0.16	0.18
LC-01	Rock	3.31	0.001	0.053	<0.01	<0.01	<2	0.002	0.003	>20	2.16	0.04	0.036	<0.001	<0.001	<0.01	4.87	0.035	0.004	0.31	1.88



BUREAU VERITAS **MINERAL LABORATORIES** Canada

www.bureauveritas.com/um

Bureau Veritas Commodities Canada Ltd.

9050 Shaughnessy St Vancouver British Columbia V6P 6E5 Canada
PHONE (604) 253-3158

Client: **Fundación Para La Transferencia Tecnológ**
Av. Beaucheff 993
Santiago Metropolitana Chile

Project: Corfo Co-Mn
Report Date: December 18, 2017

Page: 3 of 3 Part: 2 of 2

CERTIFICATE OF ANALYSIS CQQ17001336.1

		Method	**AQ370**	**AQ370**	**AQ370**	**AQ370**	**AQ370**
		Analyte	**Na**	**K**	**W**	**Hg**	**S**
		Unit	**%**	**%**	**%**	**%**	**%**
		MDL	**0.01**	**0.01**	**0.001**	**0.001**	**0.05**
TB-01	Rock		0.03	0.05	<0.001	<0.001	2.13
MN-01	Rock		0.03	0.01	<0.001	<0.001	1.79
MN-02	Rock		<0.01	0.06	<0.001	<0.001	4.18
MN-03	Rock		0.05	0.03	<0.001	<0.001	0.07
MN-04	Rock		0.02	<0.01	<0.001	<0.001	3.12
LC-01	Rock		0.05	0.05	<0.001	<0.001	0.19

BUREAU VERITAS MINERAL LABORATORIES
Canada

www.bureauveritas.com/um

Bureau Veritas Commodities Canada Ltd.
9050 Shaughnessy St Vancouver British Columbia V6P 6E5 Canada
PHONE (604) 253-3158

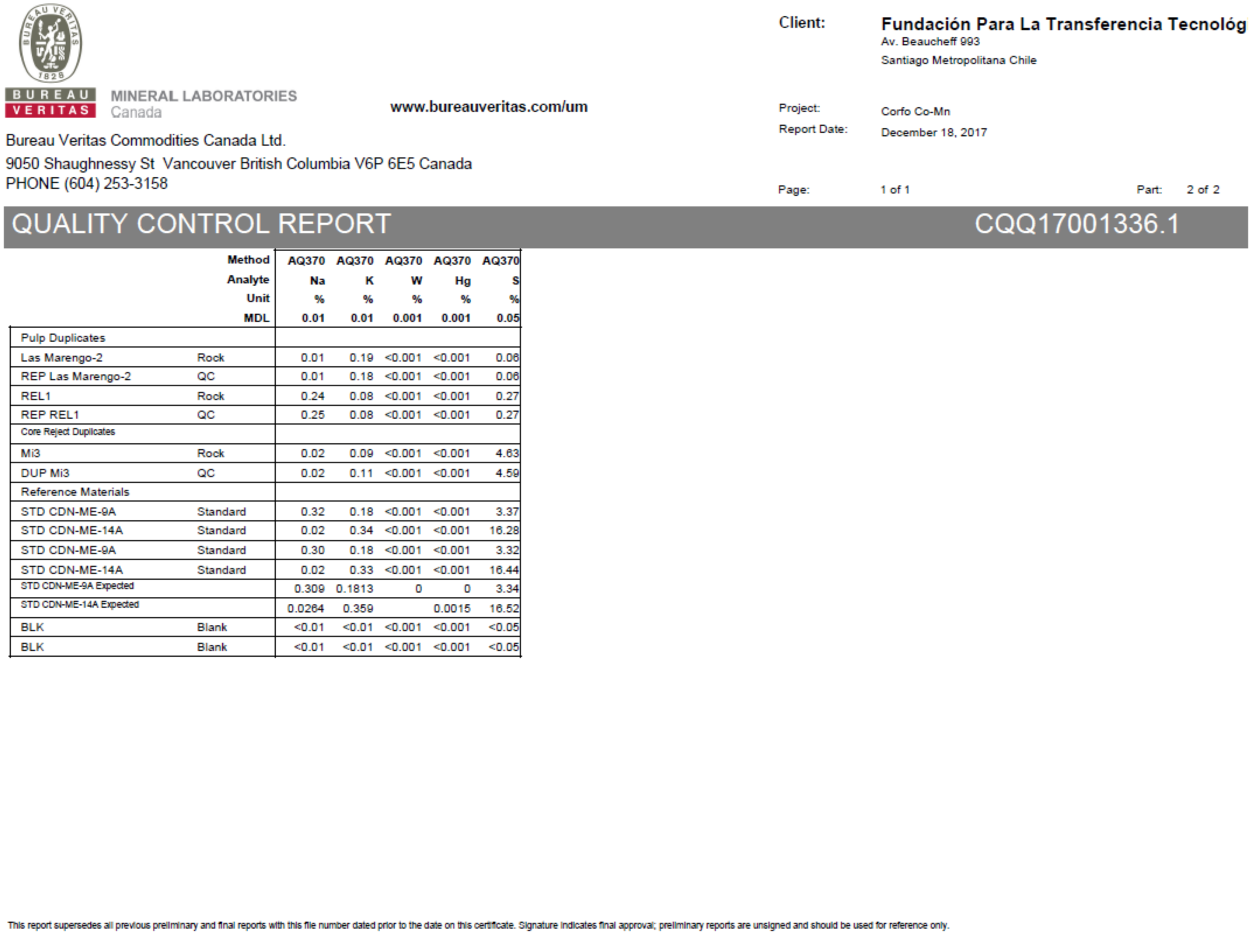
Client: **Fundación Para La Transferencia Tecnológ**
Av. Beaucheff 993
Santiago Metropolitana Chile

Project: Corfo Co-Mn
Report Date: December 18, 2017

Page: 1 of 1 Part: 1 of 2

QUALITY CONTROL REPORT CQQ17001336.1

	Method	WGHT	AQ370	AQ370	AQ370	AQ370	AQ370	AQ370	AQ370	AQ370	AQ370	AQ370	AQ370	AQ370	AQ370	AQ370	AQ370	AQ370	AQ370	AQ370	AQ370
	Analyte	Wgt	Mo	Cu	Pb	Zn	Ag	Ni	Co	Mn	Fe	As	Sr	Cd	Sb	Bi	Ca	P	Cr	Mg	Al
	Unit	kg	%	%	%	%	gm/t	%	%	%	%	%	%	%	%	%	%	%	%	%	%
	MDL	0.01	0.001	0.001	0.01	0.01	2	0.001	0.001	0.01	0.01	0.01	0.001	0.001	0.001	0.01	0.01	0.001	0.001	0.01	0.01
Pulp Duplicates																					
Las Marengo-2	Rock	3.42	0.002	1.062	<0.01	<0.01	<2	0.016	0.049	<0.01	23.68	0.23	0.003	<0.001	<0.001	<0.01	0.04	0.068	<0.001	0.03	0.50
REP Las Marengo-2	QC		0.002	1.082	<0.01	<0.01	<2	0.015	0.047	<0.01	24.25	0.23	0.002	<0.001	<0.001	<0.01	0.04	0.066	<0.001	0.02	0.49
REL1	Rock	2.94	0.008	0.129	<0.01	<0.01	<2	0.007	0.018	0.17	15.85	<0.01	0.009	<0.001	<0.001	<0.01	7.03	2.346	<0.001	3.09	2.67
REP REL1	QC		0.008	0.133	<0.01	<0.01	<2	0.007	0.013	0.17	16.28	0.02	0.009	<0.001	<0.001	<0.01	7.18	2.402	<0.001	3.17	2.73
Core Reject Duplicates																					
Mi3	Rock	2.97	0.080	0.817	0.01	<0.01	<2	0.063	>1	0.17	4.27	9.31	0.002	<0.001	0.010	<0.01	1.54	0.478	0.003	0.74	0.96
DUP Mi3	QC		0.085	0.841	0.01	<0.01	<2	0.061	>1	0.19	4.54	9.27	0.002	<0.001	0.010	<0.01	1.67	0.497	0.003	0.75	1.03
Reference Materials																					
STD CDN-ME-9A	Standard		<0.001	0.664	<0.01	<0.01	3	1.041	0.018	0.06	11.83	<0.01	0.006	<0.001	<0.001	<0.01	1.41	0.058	0.013	2.79	2.27
STD CDN-ME-14A	Standard		0.002	1.227	0.49	2.92	42	0.002	0.017	0.05	16.98	0.01	<0.001	0.009	0.002	<0.01	0.31	0.014	0.002	0.85	1.12
STD CDN-ME-9A	Standard		<0.001	0.690	<0.01	0.01	4	0.995	0.017	0.07	12.23	<0.01	0.006	<0.001	<0.001	<0.01	1.36	0.064	0.014	2.92	2.20
STD CDN-ME-14A	Standard		0.001	1.243	0.50	2.99	44	0.002	0.017	0.06	17.33	0.01	<0.001	0.009	0.003	<0.01	0.29	0.016	0.001	0.85	1.09
STD CDN-ME-9A Expected			0.00033	0.654	0.003	0.0096	3.3	0.912	0.0165	0.066	11.73	0.00125	0.006	0	0.00014	0.0002	1.37	0.0583	0.0134	2.84	2.21
STD CDN-ME-14A Expected			0.0015	1.24	0.488	2.97	42.3	0.0018	0.017	0.0589	17.29	0.0105	0.00036	0.0088	0.0024	0.0096	0.298	0.0127	0.0019	0.8787	1.14
BLK	Blank		<0.001	<0.001	<0.01	<0.01	<2	<0.001	<0.001	<0.01	<0.01	<0.01	<0.001	<0.001	<0.001	<0.01	<0.01	<0.001	<0.001	<0.01	<0.01
BLK	Blank		<0.001	<0.001	<0.01	<0.01	<2	<0.001	<0.001	<0.01	<0.01	<0.01	<0.001	<0.001	<0.001	<0.01	<0.01	<0.001	<0.001	<0.01	<0.01



Client: **Fundación Para La Transferencia Tecnológ**
Av. Beaucheff 993
Santiago Metropolitana Chile

MINERAL LABORATORIES
Canada

www.bureauveritas.com/um

Bureau Veritas Commodities Canada Ltd.
9050 Shaughnessy St Vancouver British Columbia V6P 6E5 Canada
PHONE (604) 253-3158

Project: Corfo Co-Mn
Report Date: December 18, 2017

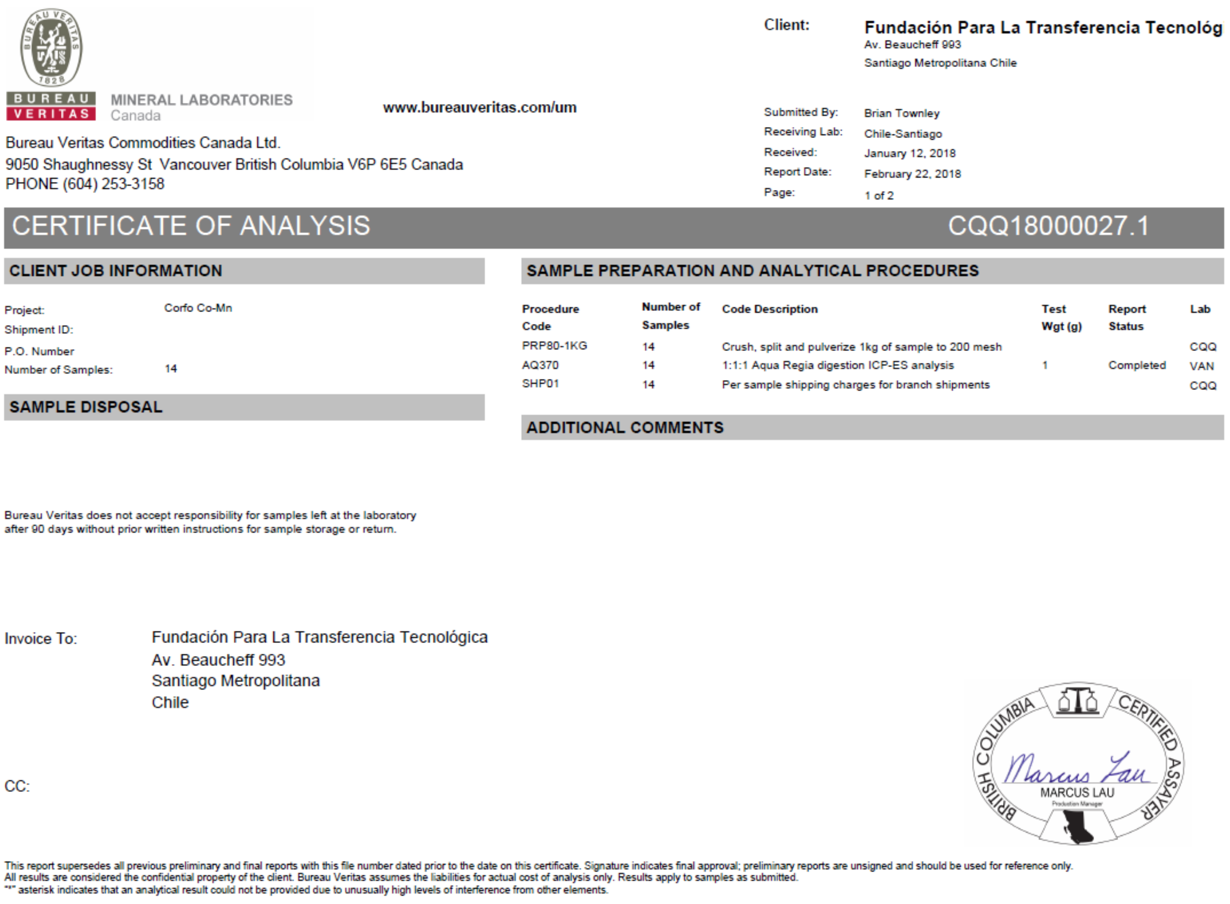
Page: 1 of 1
Part: 2 of 2

QUALITY CONTROL REPORT

CQQ17001336.1

	Method	AQ370	AQ370	AQ370	AQ370	AQ370
	Analyte	Na	K	W	Hg	S
	Unit	%	%	%	%	%
	MDL	0.01	0.01	0.001	0.001	0.05
Pulp Duplicates						
Las Marengo-2	Rock	0.01	0.19	<0.001	<0.001	0.06
REP Las Marengo-2	QC	0.01	0.18	<0.001	<0.001	0.06
REL1	Rock	0.24	0.08	<0.001	<0.001	0.27
REP REL1	QC	0.25	0.08	<0.001	<0.001	0.27
Core Reject Duplicates						
Mi3	Rock	0.02	0.09	<0.001	<0.001	4.63
DUP Mi3	QC	0.02	0.11	<0.001	<0.001	4.59
Reference Materials						
STD CDN-ME-9A	Standard	0.32	0.18	<0.001	<0.001	3.37
STD CDN-ME-14A	Standard	0.02	0.34	<0.001	<0.001	16.28
STD CDN-ME-9A	Standard	0.30	0.18	<0.001	<0.001	3.32
STD CDN-ME-14A	Standard	0.02	0.33	<0.001	<0.001	16.44
STD CDN-ME-9A Expected		0.309	0.1813	0	0	3.34
STD CDN-ME-14A Expected		0.0264	0.359		0.0015	16.52
BLK	Blank	<0.01	<0.01	<0.001	<0.001	<0.05
BLK	Blank	<0.01	<0.01	<0.001	<0.001	<0.05

This report supersedes all previous preliminary and final reports with this file number dated prior to the date on this certificate. Signature indicates final approval; preliminary reports are unsigned and should be used for reference only.



BUREAU VERITAS MINERAL LABORATORIES Canada

www.bureauveritas.com/um

Bureau Veritas Commodities Canada Ltd.
9050 Shaughnessy St Vancouver British Columbia V6P 6E5 Canada
PHONE (604) 253-3158

Client: **Fundación Para La Transferencia Tecnológ**
Av. Beaucheff 993
Santiago Metropolitana Chile

Submitted By: Brian Townley
Receiving Lab: Chile-Santiago
Received: January 12, 2018
Report Date: February 22, 2018
Page: 1 of 2

CERTIFICATE OF ANALYSIS CQQ18000027.1

CLIENT JOB INFORMATION

Project:	Corfo Co-Mn
Shipment ID:	
P.O. Number	
Number of Samples:	14

SAMPLE DISPOSAL

Bureau Veritas does not accept responsibility for samples left at the laboratory after 90 days without prior written instructions for sample storage or return.

SAMPLE PREPARATION AND ANALYTICAL PROCEDURES

Procedure Code	Number of Samples	Code Description	Test Wgt (g)	Report Status	Lab
PRP80-1KG	14	Crush, split and pulverize 1kg of sample to 200 mesh			CQQ
AQ370	14	1:1:1 Aqua Regia digestion ICP-ES analysis	1	Completed	VAN
SHP01	14	Per sample shipping charges for branch shipments			CQQ

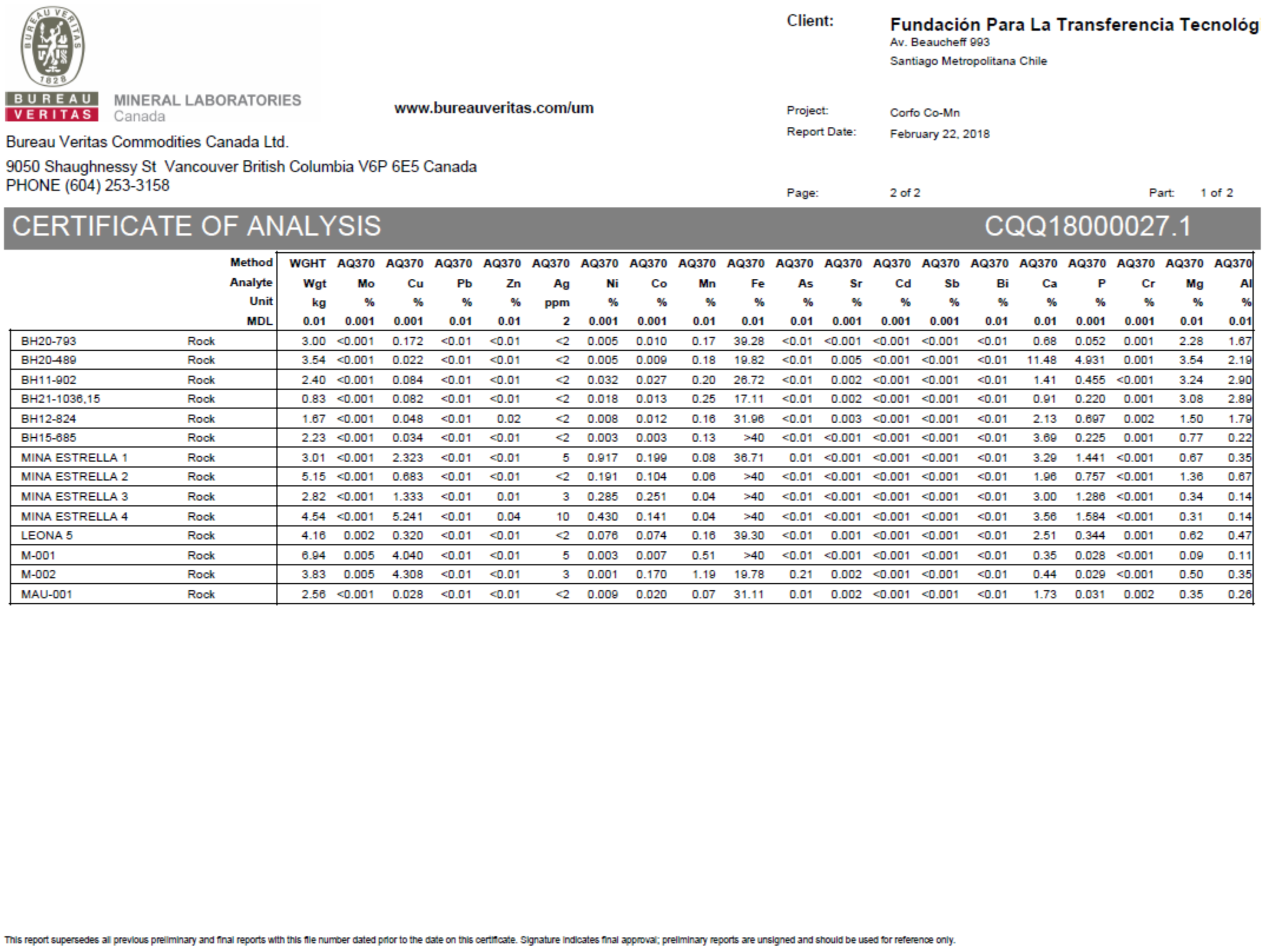
ADDITIONAL COMMENTS

Invoice To: Fundación Para La Transferencia Tecnológica
Av. Beaucheff 993
Santiago Metropolitana
Chile

CC:

Marcus Lau
MARCUS LAU

This report supersedes all previous preliminary and final reports with this file number dated prior to the date on this certificate. Signature indicates final approval; preliminary reports are unsigned and should be used for reference only.
All results are considered the confidential property of the client. Bureau Veritas assumes the liabilities for actual cost of analysis only. Results apply to samples as submitted.
"*" asterisk indicates that an analytical result could not be provided due to unusually high levels of interference from other elements.



BUREAU VERITAS MINERAL LABORATORIES Canada

www.bureauveritas.com/um

Bureau Veritas Commodities Canada Ltd.

9050 Shaughnessy St Vancouver British Columbia V6P 6E5 Canada
PHONE (604) 253-3158

Client: **Fundación Para La Transferencia Tecnológ**
Av. Beaucheff 993
Santiago Metropolitana Chile

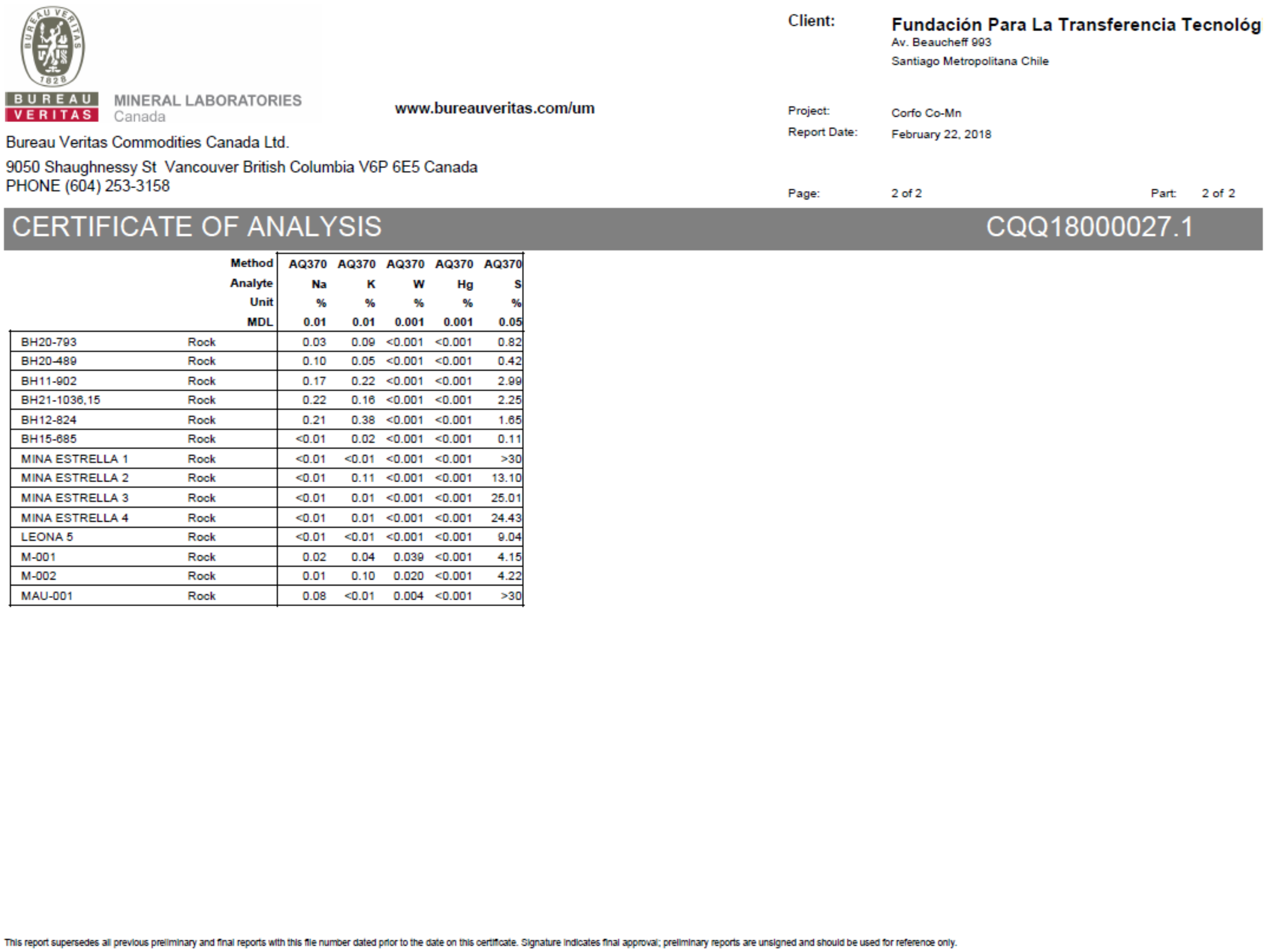
Project: Corfo Co-Mn
Report Date: February 22, 2018

Page: 2 of 2
Part: 1 of 2

CERTIFICATE OF ANALYSIS CQQ18000027.1

	Method	WGHT	AQ370	AQ370	AQ370	AQ370	AQ370	AQ370	AQ370	AQ370	AQ370	AQ370	AQ370	AQ370	AQ370	AQ370	AQ370	AQ370	AQ370	AQ370	AQ370
	Analyte	Wgt	Mo	Cu	Pb	Zn	Ag	Ni	Co	Mn	Fe	As	Sr	Cd	Sb	Bi	Ca	P	Cr	Mg	Al
	Unit	kg	%	%	%	%	ppm	%	%	%	%	%	%	%	%	%	%	%	%	%	%
	MDL	0.01	0.001	0.001	0.01	0.01	2	0.001	0.001	0.01	0.01	0.01	0.001	0.001	0.001	0.01	0.01	0.001	0.001	0.01	0.01
BH20-793	Rock	3.00	<0.001	0.172	<0.01	<0.01	<2	0.005	0.010	0.17	39.28	<0.01	<0.001	<0.001	<0.001	<0.01	0.68	0.052	0.001	2.28	1.67
BH20-489	Rock	3.54	<0.001	0.022	<0.01	<0.01	<2	0.005	0.009	0.18	19.82	<0.01	0.005	<0.001	<0.001	<0.01	11.48	4.931	0.001	3.54	2.19
BH11-902	Rock	2.40	<0.001	0.084	<0.01	<0.01	<2	0.032	0.027	0.20	26.72	<0.01	0.002	<0.001	<0.001	<0.01	1.41	0.455	<0.001	3.24	2.90
BH21-1036,15	Rock	0.83	<0.001	0.082	<0.01	<0.01	<2	0.018	0.013	0.25	17.11	<0.01	0.002	<0.001	<0.001	<0.01	0.91	0.220	0.001	3.08	2.89
BH12-824	Rock	1.67	<0.001	0.048	<0.01	0.02	<2	0.008	0.012	0.16	31.96	<0.01	0.003	<0.001	<0.001	<0.01	2.13	0.697	0.002	1.50	1.79
BH15-685	Rock	2.23	<0.001	0.034	<0.01	<0.01	<2	0.003	0.003	0.13	>40	<0.01	<0.001	<0.001	<0.001	<0.01	3.69	0.225	0.001	0.77	0.22
MINA ESTRELLA 1	Rock	3.01	<0.001	2.323	<0.01	<0.01	5	0.917	0.199	0.08	36.71	0.01	<0.001	<0.001	<0.001	<0.01	3.29	1.441	<0.001	0.67	0.35
MINA ESTRELLA 2	Rock	5.15	<0.001	0.683	<0.01	<0.01	<2	0.191	0.104	0.06	>40	<0.01	<0.001	<0.001	<0.001	<0.01	1.96	0.757	<0.001	1.36	0.67
MINA ESTRELLA 3	Rock	2.82	<0.001	1.333	<0.01	0.01	3	0.285	0.251	0.04	>40	<0.01	<0.001	<0.001	<0.001	<0.01	3.00	1.286	<0.001	0.34	0.14
MINA ESTRELLA 4	Rock	4.54	<0.001	5.241	<0.01	0.04	10	0.430	0.141	0.04	>40	<0.01	<0.001	<0.001	<0.001	<0.01	3.56	1.584	<0.001	0.31	0.14
LEONA 5	Rock	4.16	0.002	0.320	<0.01	<0.01	<2	0.076	0.074	0.16	39.30	<0.01	0.001	<0.001	<0.001	<0.01	2.51	0.344	0.001	0.62	0.47
M-001	Rock	6.94	0.005	4.040	<0.01	<0.01	5	0.003	0.007	0.51	>40	<0.01	<0.001	<0.001	<0.001	<0.01	0.35	0.028	<0.001	0.09	0.11
M-002	Rock	3.83	0.005	4.308	<0.01	<0.01	3	0.001	0.170	1.19	19.78	0.21	0.002	<0.001	<0.001	<0.01	0.44	0.029	<0.001	0.50	0.35
MAU-001	Rock	2.56	<0.001	0.028	<0.01	<0.01	<2	0.009	0.020	0.07	31.11	0.01	0.002	<0.001	<0.001	<0.01	1.73	0.031	0.002	0.35	0.26

This report supersedes all previous preliminary and final reports with this file number dated prior to the date on this certificate. Signature indicates final approval; preliminary reports are unsigned and should be used for reference only.



BUREAU VERITAS **MINERAL LABORATORIES** Canada

www.bureauveritas.com/um

Bureau Veritas Commodities Canada Ltd.

9050 Shaughnessy St Vancouver British Columbia V6P 6E5 Canada
PHONE (604) 253-3158

Client: **Fundación Para La Transferencia Tecnológ**
Av. Beaucheff 993
Santiago Metropolitana Chile

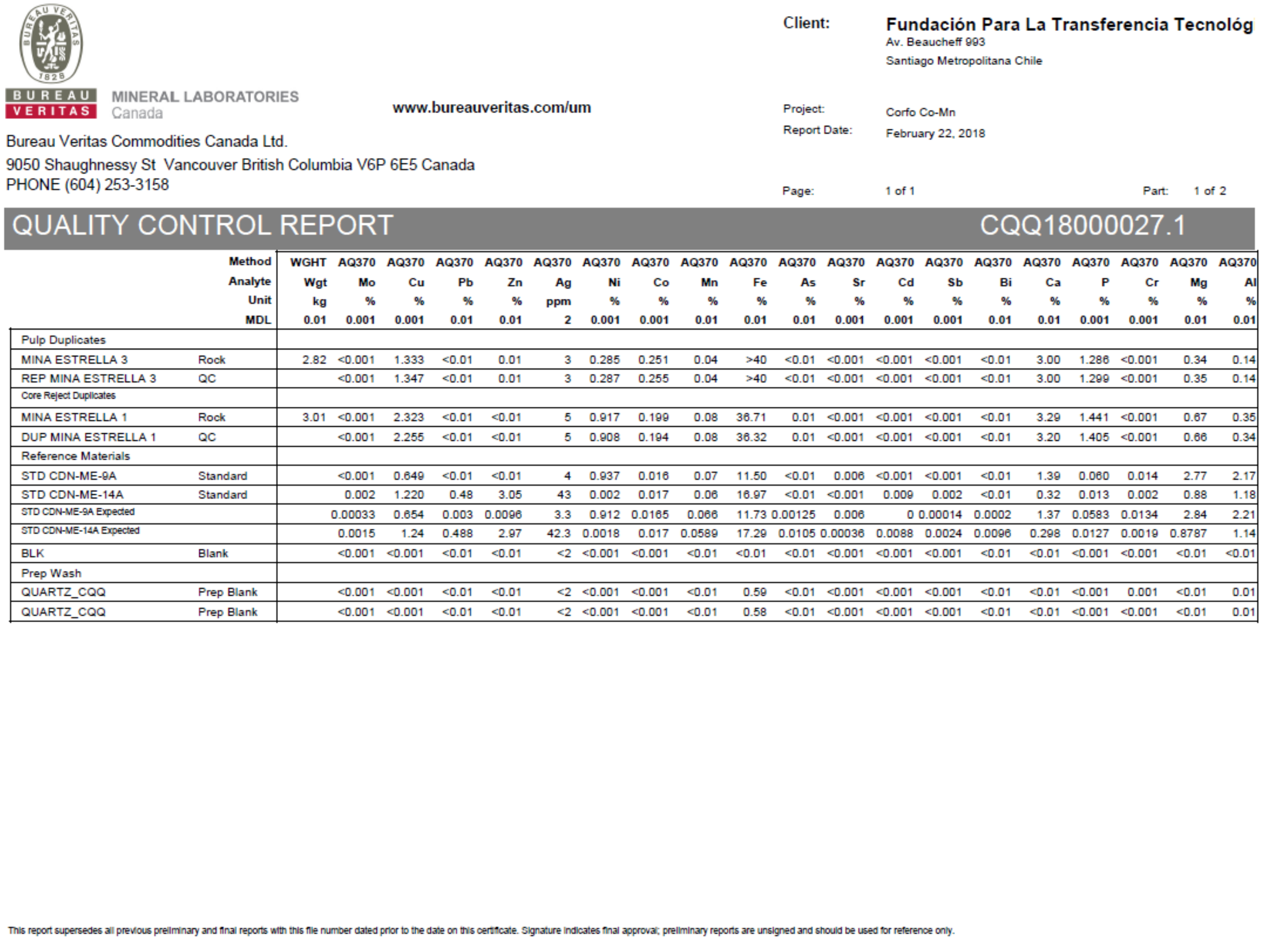
Project: Corfo Co-Mn
Report Date: February 22, 2018

Page: 2 of 2 Part: 2 of 2

CERTIFICATE OF ANALYSIS CQQ18000027.1

	Method	AQ370	AQ370	AQ370	AQ370	AQ370
	Analyte	**Na**	**K**	**W**	**Hg**	**S**
	Unit	**%**	**%**	**%**	**%**	**%**
	MDL	**0.01**	**0.01**	**0.001**	**0.001**	**0.05**
BH20-793	Rock	0.03	0.09	<0.001	<0.001	0.82
BH20-489	Rock	0.10	0.05	<0.001	<0.001	0.42
BH11-902	Rock	0.17	0.22	<0.001	<0.001	2.99
BH21-1036,15	Rock	0.22	0.16	<0.001	<0.001	2.25
BH12-824	Rock	0.21	0.38	<0.001	<0.001	1.65
BH15-685	Rock	<0.01	0.02	<0.001	<0.001	0.11
MINA ESTRELLA 1	Rock	<0.01	<0.01	<0.001	<0.001	>30
MINA ESTRELLA 2	Rock	<0.01	0.11	<0.001	<0.001	13.10
MINA ESTRELLA 3	Rock	<0.01	0.01	<0.001	<0.001	25.01
MINA ESTRELLA 4	Rock	<0.01	0.01	<0.001	<0.001	24.43
LEONA 5	Rock	<0.01	<0.01	<0.001	<0.001	9.04
M-001	Rock	0.02	0.04	0.039	<0.001	4.15
M-002	Rock	0.01	0.10	0.020	<0.001	4.22
MAU-001	Rock	0.08	<0.01	0.004	<0.001	>30

This report supersedes all previous preliminary and final reports with this file number dated prior to the date on this certificate. Signature indicates final approval; preliminary reports are unsigned and should be used for reference only.



BUREAU VERITAS MINERAL LABORATORIES Canada

www.bureauveritas.com/um

Bureau Veritas Commodities Canada Ltd.
9050 Shaughnessy St Vancouver British Columbia V6P 6E5 Canada
PHONE (604) 253-3158

Client: **Fundación Para La Transferencia Tecnológ**
Av. Beaucheff 993
Santiago Metropolitana Chile

Project: Corfo Co-Mn
Report Date: February 22, 2018

Page: 1 of 1
Part: 1 of 2

QUALITY CONTROL REPORT CQQ18000027.1

	Method	WGHT	AQ370	AQ370	AQ370	AQ370	AQ370	AQ370	AQ370	AQ370	AQ370	AQ370	AQ370	AQ370	AQ370	AQ370	AQ370	AQ370	AQ370	AQ370	AQ370
	Analyte	Wgt	Mo	Cu	Pb	Zn	Ag	Ni	Co	Mn	Fe	As	Sr	Cd	Sb	Bi	Ca	P	Cr	Mg	Al
	Unit	kg	%	%	%	%	ppm	%	%	%	%	%	%	%	%	%	%	%	%	%	%
	MDL	0.01	0.001	0.001	0.01	0.01	2	0.001	0.001	0.01	0.01	0.01	0.001	0.001	0.001	0.01	0.01	0.001	0.001	0.01	0.01
Pulp Duplicates																					
MINA ESTRELLA 3	Rock	2.82	<0.001	1.333	<0.01	0.01	3	0.285	0.251	0.04	>40	<0.01	<0.001	<0.001	<0.001	<0.01	3.00	1.286	<0.001	0.34	0.14
REP MINA ESTRELLA 3	QC		<0.001	1.347	<0.01	0.01	3	0.287	0.255	0.04	>40	<0.01	<0.001	<0.001	<0.001	<0.01	3.00	1.299	<0.001	0.35	0.14
Core Reject Duplicates																					
MINA ESTRELLA 1	Rock	3.01	<0.001	2.323	<0.01	<0.01	5	0.917	0.199	0.08	36.71	0.01	<0.001	<0.001	<0.001	<0.01	3.29	1.441	<0.001	0.67	0.35
DUP MINA ESTRELLA 1	QC		<0.001	2.255	<0.01	<0.01	5	0.908	0.194	0.08	36.32	0.01	<0.001	<0.001	<0.001	<0.01	3.20	1.405	<0.001	0.66	0.34
Reference Materials																					
STD CDN-ME-9A	Standard		<0.001	0.649	<0.01	<0.01	4	0.937	0.016	0.07	11.50	<0.01	0.006	<0.001	<0.001	<0.01	1.39	0.060	0.014	2.77	2.17
STD CDN-ME-14A	Standard		0.002	1.220	0.48	3.05	43	0.002	0.017	0.06	16.97	<0.01	<0.001	0.009	0.002	<0.01	0.32	0.013	0.002	0.88	1.18
STD CDN-ME-9A Expected			0.00033	0.654	0.003	0.0096	3.3	0.912	0.0165	0.066	11.73	0.00125	0.006	0	0.00014	0.0002	1.37	0.0583	0.0134	2.84	2.21
STD CDN-ME-14A Expected			0.0015	1.24	0.488	2.97	42.3	0.0018	0.017	0.0589	17.29	0.0105	0.00036	0.0088	0.0024	0.0096	0.298	0.0127	0.0019	0.8787	1.14
BLK	Blank		<0.001	<0.001	<0.01	<0.01	<2	<0.001	<0.001	<0.01	<0.01	<0.01	<0.001	<0.001	<0.001	<0.01	<0.01	<0.001	<0.001	<0.01	<0.01
Prep Wash																					
QUARTZ_CQQ	Prep Blank		<0.001	<0.001	<0.01	<0.01	<2	<0.001	<0.001	<0.01	0.59	<0.01	<0.001	<0.001	<0.001	<0.01	<0.01	<0.001	0.001	<0.01	0.01
QUARTZ_CQQ	Prep Blank		<0.001	<0.001	<0.01	<0.01	<2	<0.001	<0.001	<0.01	0.58	<0.01	<0.001	<0.001	<0.001	<0.01	<0.01	<0.001	<0.001	<0.01	0.01

This report supersedes all previous preliminary and final reports with this file number dated prior to the date on this certificate. Signature indicates final approval; preliminary reports are unsigned and should be used for reference only.

BUREAU VERITAS MINERAL LABORATORIES
Canada

www.bureauveritas.com/um

Bureau Veritas Commodities Canada Ltd.
9050 Shaughnessy St Vancouver British Columbia V6P 6E5 Canada
PHONE (604) 253-3158

Client: **Fundación Para La Transferencia Tecnológ**
Av. Beaucheff 993
Santiago Metropolitana Chile

Project: Corfo Co-Mn
Report Date: February 22, 2018

Page: 1 of 1
Part: 2 of 2

QUALITY CONTROL REPORT CQQ18000027.1

	Method	AQ370	AQ370	AQ370	AQ370	AQ370
	Analyte	Na	K	W	Hg	S
	Unit	%	%	%	%	%
	MDL	0.01	0.01	0.001	0.001	0.05
Pulp Duplicates						
MINA ESTRELLA 3	Rock	<0.01	0.01	<0.001	<0.001	25.01
REP MINA ESTRELLA 3	QC	<0.01	0.01	<0.001	<0.001	24.95
Core Reject Duplicates						
MINA ESTRELLA 1	Rock	<0.01	<0.01	<0.001	<0.001	>30
DUP MINA ESTRELLA 1	QC	<0.01	<0.01	<0.001	<0.001	29.52
Reference Materials						
STD CDN-ME-9A	Standard	0.32	0.19	<0.001	<0.001	3.37
STD CDN-ME-14A	Standard	0.03	0.39	<0.001	<0.001	16.63
STD CDN-ME-9A Expected		0.309	0.1813	0	0	3.34
STD CDN-ME-14A Expected		0.0264	0.359		0.0015	16.52
BLK	Blank	<0.01	<0.01	<0.001	<0.001	<0.05
Prep Wash						
QUARTZ_CQQ	Prep Blank	<0.01	0.01	<0.001	<0.001	<0.05
QUARTZ_CQQ	Prep Blank	<0.01	0.01	<0.001	<0.001	<0.05