Assessing Mineral Potential in Bolivia; Phase I

By

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Abstract

Bolivia, located in the west-central part of South America, has extracted only a small amount of its total economic mineral potential, making it an ideal place for economic opportunity. The Bolivian Tin Belt, for example, contains some of the world’s largest Sn/Ag porphyry granite systems in the world. Sinchi Wayra, S. A., Emicruz LTD, Comsur, Zonge, Engineering and Sander Geophysics LTD provided Landsat™, geochemical and geophysical data in hopes of determining phase I locations for potential economic mineral extraction. This work is the initial stage of more desktop studies and field work.

Unreliability in ratioing of the Landsat™ images reduced the number of indices that could be created. Layer stacking of Landsat™ images from the Potosi region (in the red, green and blue of clay, ferrous minerals and iron oxides respectively) revealed a few areas of high iron content (moderate adjacent clay minerals) that deserved further attention. Only a few ratio images coincided with areas of sufficient rock chip sampling. However, in all cases, the ratio images matched the described alteration (from rock chip sampling).

Geochemical data revealed two locations of economic mineralization and fourteen other locations with enough potential for further study. Most of the areas of mineral potential are located within or adjacent to the Bolivian Tin Belt, in the central and southern portions of the Eastern Cordillera, and show anomalous values of As, Bi, Sb, Ag, Sn, Pb, Zn, W, Cu and/or Au. The majority of these mineral occurrences are epithermal polymetallic vein deposits related to felsic or intermediate porphyrytic/equigranular intrusions.

Radiometric data revealed at least one major site of interest with elevated U and Th values near the Boliva-Brazil border. Several other anomalies (based on airborne magnetics) revealed strong dipoles in eastern Potosi and in southeastern Bolivia.
Chapter 1. Introduction

We received a data set consisting of approximately 20 CDs of Landsat™ images, geophysical data, and geochemical data (provided by Comsur, Zonge Engineering and Sander Geophysics LTD) collected by various geologists and contractors since 1992. The data were provided by Carlos Birbuet and funded by Sinchi Wayra S. A. with the goal of a detailed analysis of the completeness and usability of the data and a preliminary assessment of the suitability of the data to find more prospective mineralized areas within Bolivia. The goal of this thesis is to determine geochemical patterns that may be associated with mineralization and correlate those patterns with ancillary Landsat™ images and airborne geophysical data.

Landsat™ images, geochemical (rock and soil) and geophysical data all play important roles in locating zones of economic mineral potential. Comsur, Zonge Engineering and Sander Geophysics LTD provided Landsat™ images within the data set and cover an area approximately equal to 32,000 km², making an initial analysis of surface geology manageable. Ratioing of certain bands within the images, such as band 5 (1.55 to 1.75 µm) divided by band 7 (2.08 to 2.35 µm), and then creating layer stacks allows the interpreter to locate areas of high clay content based on the output colors. Clay minerals absorb spectral energy within the range of band 7 and reflect more spectral energy in band 5. As a result, if clay is exposed on the surface, then these areas should respond with a high (bright) digital number (DN). Structural trends within an image may also be enhanced. Many mineral deposits occur within or at the intersection of faults and locating major fault trends may lead to the discovery of new mineral deposits. A total of six Landsat™ images LTD provided by Comsur, Zonge, Engineering and Sander Geophysics were analyzed that covered the southern portion of the Eastern Cordillera, the Santa Cruz region of Bolivia’s plains and eastern Bolivia, partially overlapping the Bolivian-Brazilian border near the Brazilian city of Corumba.

Geochemical data are critical to the discovery and development of economic mineral deposits. Three sets of soil data were analyzed from the Cachi Laguna volcanic complex, near San Vincente, and a wide zone in the Santa Cruz region. Erosion of rock material and the formation of soils act to disperse various elements in distinct way. Soil sample data may yield spikes of particular chemical species in
certain locations, indicating the presence of a near surface mineralized ore body. Outcrop and drill core samples, on the other hand, give clues as to the nature of alteration, rock type and weight percentages of various chemical species within their present location. Firsthand knowledge of mineralization may lead to further geophysical exploration.

Ground-based induced polarization (IP) methods help to establish the dimensions of a sulfide body by measuring the resistivity and chargeability of underlying rocks. Airborne geophysical studies measure magnetic intensity (in order to located highly magnetic bodies) as well as uranium (U), thorium (Th) and potassium (K) surface values. K measurements may lead to the discovery of high temperature alteration areas while U and Th studies aim to determine possible locations of anomalously high rare earth elements accompanied by economic minerals of interest (Cu-bearing minerals for example). Radiometric data covered the central portion of the Eastern Cordillera, western Santa Cruz region and eastern Bolivia (near the Bolivia-Brazil border).

Of the total mineral potential in Bolivia only a minimal amount has likely been exploited. As a result the potential exists for a significant number of undiscovered economic mineral deposits to be discovered throughout Bolivia. Companies such as Comsur, Emicruz, Zonge Engineering and Sander Geophysics LTD conducted the majority of surveys. Only a few of the geochemical surveys, geophysical surveys and satellite imagery were strategic based upon previously known areas of economic mineral production. The majority of the surveys appear to be reconnaissance work.

The primary focus of this thesis is on the geochemical data from the Andes Mountains. While geophysical data and satellite imagery aid in determining areas of mineral potential the geochemical data provided valuable insight into possible ore zone locations and types of ore present. The geochemical data provide a much better starting point with which to look for ore deposits and analyze geologic data from a first order approach. The geochemical data provide a much better starting point with which to look for ore deposits and analyze geologic data from a first order approach.
1.1 Study Area

With such a small percentage of Bolivia’s economic mineralization exploited the study area spans most country from west to east with the exception of the northern Bolivian Andes and Pando Plain. Landsat™ images primarily occupy the southern half of Bolivia with two images covering the Andes (below Sucre), three images covering the Chaco-Beni-Tarija Plains (one image south of Trinidad and two east of the Santa Cruz region) and one image occupying the Tarija plain within Paraguay (overlapping a section of the Bolivia-Paraguay border) (Figure 1). One image covered the region of Potosi where a portion of the Bolivian Tin Belt exists.
Geochemical sampling focused on various locations within the Andes Mountains. One of the prime areas of geochemical exploration took place within and near the Bolivian Tin Belt. Drill core samples were taken from areas of known economic mineral potential such as at Tollocci, San Florencio and Cachi Laguna volcano. Other geochemical data were collected from soils, float and outcrops. Due to the rugged terrain of the Andes the vast majority of samples were either derived from float or outcrops. Eastern Bolivia, on the other hand, is relatively flat and receives much more rainfall, leading to greater vegetation growth and soil development. As a result a higher percentage of soil samples were collected.

Geophysical studies were dispersed throughout much of Bolivia. IP, magnetic, U, Th and K studies were conducted within Northern Potosi where geochemical sampling established some economic potential. Much of eastern Bolivia was studied for magnetic intensity, U, Th and K.
Chapter 2. Geologic Setting

The Andean orogenic belt is one of the most impressive topographic features on Earth, with a length of >7000 km, a maximum width of ~800 km and peak elevations greater than 6.7 km (DeCelles et al. 2003). The Bolivian section of the Andes covers a distance on the order of 800 km in terms of strike length and reaches a width greater than 700 km. While the Altiplano region resides at an average elevation of approximately 4,000 m the entire mountain system reaches an average elevation of about 4,500 m.

2.1 Tectonics

The Nazca plate is located to the west of South America. Oblique convergence between the Nazca and South American plate has resulted in the overthrusting of continental shelf sediments on top of older cratonic material coupled with the creation of new crustal igneous material generated from slab induced mantle wedge partial fusion (Figure 2). Temporal variations in the angle of subduction has caused the frontal fold and thrust belt to vary spatially in the east-west direction. As a result mutually exclusive mountain building events have occurred in the western and eastern sections of the Andes Mountains. Present estimates approximate convergence at 77 mm/yr. Based on GPS data about 10-15 mm/yr of crustal shortening occurs inland at the sub-Andean foreland fold and thrust belt, indicating that the Andes are continuing to build (UNAVCO Brochure Online 1998). This shortening rate is significantly greater than inferred from seismic moments, suggesting that the shortening is largely aseismic.

One of the major problems geologist face while studying the Andes is to accurately constrain the timing of mountain formation. Although evidence for Cretaceous rifting in the central Andes is present in northern Argentina and locally in southern Bolivia, the timing of the transition from regional extension to shortening remains ambiguous. Some authors maintain that the transition occurred during Late Cretaceous or early Paleocene time (e.g., Sempere et al., 1997; Horton et al., 2001), whereas others contend that
Regional shortening did not begin until the Eocene (Welsink et al., 1995; Lamb et al., 1997; Lamb and Hoke, 1997; Viramonte et al., 1999) or possibly later (Jordan et al., 1997, 2001).

The Coastal Cordillera is mainly comprised of accretionary wedge and scattered forearc sediments (depending upon the particular location). Much of this sediment accumulation results from the transportation of eroded marginal Western Cordillera material.

Directly east of the Coastal Cordillera resides the Western Cordillera, which consists of high (5–6.5 km) Miocene–Quaternary stratovolcanoes and ignimbrite sheets (DeCelles et al. 2003). Hence, the Western Cordillera characterizes the magmatic and volcanically active portion of the Andes Mountains.

Figure 2. USGS (1997) image of major plate boundaries (modified from Tilling, Heliker, and Wright, 1987, and Hamilton, 1976). The Nazca plate borders the South American plate.

According to previous studies by DeCelles (2003) the geology of the Bolivian Andes is divisible into six longitudinal tectonomorphic zones. However, depending upon a person’s definition of a "tectonomorphic zone" one could argue that approximately seven total tectonomorphic zones exist (Figure
3). From west to east the seven major zones include the Coastal Cordillera, Western Cordillera, Altiplano, Eastern Cordillera, Interandean region, Subandean ranges, and Chaco Plain. Each zone resulted from various and, sometimes, mutually exclusive tectonic events.

Figure 3. Image of major tectonomorphic zones within Bolivian Andes (from Jacobhagen et al, 2001). The majority of the geochemical, geophysical and Landsat™ data comes from the Cordillera Oriental (Eastern Cordillera), Interandean zone and Subandean range.
The Altiplano resides east of the Western Cordillera and is considered one of the world’s most kinematically perplexing plateaus. It comprises an area approximately 300,000 km$^2$ with an average elevation around 4 km. The plateau also hosts the world’s largest salt flat (approximately 3,000,000 acres) called the Salar de Uyuni (Petrov et al., 2003). Salar de Uyuni resides at the lowest elevation in the Altiplano at approximately 3.6 km. The rest of the area comprising the Altiplano is composed of Quaternary sediment, as well as local Cenozoic, Mesozoic, and Paleozoic sedimentary outcrops along the northern and eastern parts of the Altiplano. These rocks have been subject to significant horizontal shortening (Lamb and Hoke, 1997; McQuarrie and DeCelles, 2001; McQuarrie, 2002).

East of the Altiplano is the Eastern Cordillera. This region contains a bivergent fold-thrust belt primarily composed of Ordovician–Devonian sedimentary rocks, overlain locally by Permian, Jurassic, and Cretaceous strata accompanied by local accumulations of Cenozoic strata (DeCelles et al. 2003). Despite the large amounts of sedimentary rocks present perhaps the Eastern Cordillera is more well-known for its tin-silver porphyry granite systems. The Bolivian Tin Belt, as it is called, stretches 1000 km in (strike) length and contains minor 220 Ma old tin granite systems (Chacaltaya, Chojlla) and major 25 to 12 Ma old tin granite/porphyry systems (Grant et al. 1979). The Bolivian Tin Belt has produced some of the largest quantities of tin and silver in the world.

The eastern part of the Eastern Cordillera is referred to as the Interandean zone and consists of Silurian–Devonian strata carried by east-directed thrust faults (Kley, 1996; Schmitz and Kley, 1997; McQuarrie, 2002). East of the Interandean zone lies the Subandean zone, which is the active frontal part of the fold-thrust belt (Dunn et al., 1995). Farther east resides the Chaco Plain, comprising most of the wedge-top and foredeep depozones of the modern, central Andean foreland basin system (Horton and DeCelles, 1997). In select locations within the Chaco Plain (primarily towards the Bolivia-Brazil border) Precambrian basement, undifferentiated Paleozoic granitoids, deformed sediments, and undifferentiated ultramafic rocks are exposed at the surface.
2.2 Magmatic Processes, Petrology and Sedimentary Rocks

2.2.1 Bolivian Andes

The Eastern Cordillera in Bolivia occupies the back-arc portion of the central Andes and hosts the vast majority of the country’s ore deposits. It represents one of the great strongly peraluminous (i.e. containing a greater molecular proportion of aluminum oxide than sodium oxide and potassium oxide combined) igneous provinces of the world, and is one of few such regions bearing voluminous silicic peraluminous volcanic rocks (Morgan et al., 1998). One major factor contributing to the production of the voluminous silicic peraluminous material is the partial fusion of the mantle wedge.

As mentioned earlier the Bolivian Tin Belt (Figure 4) contains minor 220 Ma tin granite systems (Chacaltaya and Chojilla) and major 25 to 12 Ma old tin granite/porphyry systems (Grant et al., 1979). The tin-silver deposits are typically associated with felsic volcanic domes of broadly rhyodacitic composition (Cunningham et al., 1991). Most deposits are characteristically of vein type, with the ore comprising polymetallic massive sulfides accompanied by only relatively minor amounts of gangue (Turneaure et al., 1960; Ludington et al., 1992). However, mineralized veinlet stockworks and hydrothermal breccias are also commonplace. Well-developed metal zoning typifies many of the vein systems, with base metals and silver tending to increase both upwards and outwards at the expense of tin, bismuth and tungsten (Turneaure et al., 1960).

Plutonic rocks in the tin belt are mostly peraluminous and contain high levels of large ion lithophile elements such as Rh, Li, Cs, B, and Sn (Morgan et al., 1998). Boron enrichment may have resulted from partial melting of pelitic source lithologies because shales are approximately ten times enriched in boron compared to average continental crust (crustal average ≈ 10 ppm, shales ≈ 100 ppm). According to Lehman (2000) the average boron content in melt inclusions of quartz phenocrysts from Bolivian tin porphyry systems is 225 ppm (1C-variation range: 110-420 ppm; n=12) and suggests a
magmatic boron input to the hydrothermal tin systems, and not shallow post-magmatic leaching of boron from pelitic country rocks. High boron contents are typical features of the magmatic-hydrothermal systems of the Bolivian tin province.

Figure 4. Drawing of the Bolivian Tin Belt (from Lehman et al. 2000). The tin belt host some of the world’s largest tin-silver deposits and as well as Pb, Zn and Au ores.

Other melt inclusion data in quartz phenocrysts from Bolivian tin porphyry systems indicate a highly fractionated rhyolitic composition, distinctly different from the rhyodacitic bulk rock geochemistry (Dietrich et al., 1999). The melt inclusion geochemistry (electron and proton microprobe analysis) points to mixing of a highly evolved rhyolitic melt with andesitic to basaltic melt portions in an upper crustal
reservoir (Dietrich et al., 1999). Such a mixing process can induce catastrophic volatile exsolution and may be the controlling factor not only in tin porphyries but also for the metallogeny of other porphyry systems.

Further evidence of magma mixing and crustal assimilation can be found through analyzing neodymium isotopic data. Average εNd values taken from Bolivian tin porphyry systems range from -5 to -10 (Lehman et al., 2000). This indicates that the rocks were derived from sources that had a lower Sm/Nd ratio than the chondritic reservoir. Hence the rocks were derived from, or assimilated, older crustal rocks where the Sm/Nd had been lowered originally when they separated from CHUR.

Early hydrothermal alteration mostly produced the mineral association quartz-sericite-tourmaline-pyrite. Hydrothermal mineral association of the ore deposits in the tin belt contain cassiterite as the dominant Sn mineral and a variety of Ag, Sb, As, Cu, Pb, Zn, and Bi sulfides, with locally elevated Au contents (Lehman et al., 2000).

### 2.2.2 Sedimentary Rocks

Sedimentary rocks contribute much of the material comprising the Altiplano and Eastern Cordillera. In fact the Bolivian section of the Altiplano hosts the world’s largest salt flat. Salar de Uyuni (Figure 5) comprises an area on the order of 12,000 square kilometers and is the remnant of a large prehistoric lake called Lake Minchín. At an elevation of 3,650 km the Salar de Uyuni resides in the lowest section of the Altiplano (Petrov et al., 2003). Located within the extensive salt flat resides a handful of pyroclastic flow deposits and stromatolite outcrops. Overall the Altiplano hosts a few dozen salt flats. The Altiplano resides between two topographically high tectonic regions, the Western and Eastern Cordillera. As a result it serves as a large drainage basement, collecting sediment runoff from all directions.

In contrast to the Western Cordillera, where volcanic rocks dominate the landscape, the Eastern Cordillera is dominated by lower Paleozoic clastic rocks. The clastic rocks include shales, mudstones, siltstones and sandstones along with metamorphosed quartzites and smaller amounts of dolomites and
limestones. The sedimentary rocks are primarily shallow sea and tidal derived. Textures range from fine to course grained and planar laminated to massive.

Figure 5. Graphic displaying Salar de Uyuni and surrounding salt flats and lakes. (from http://www.welt.atlas.com/).

2.3 Eastern Bolivia

Much of the geology east of the Andes Mountains is obscured by Tertiary and Quaternary sediments shed off the eastern section (Eastern Cordillera, Interandean zone and Subandean zone) of the world’s second highest mountain range. Exposed basement material and fault systems yield clues into the
violent past of this region. Multiple accretion events along with generation of new material generally define much of the process that took place to form the older basement material.

Figure 6. Drawing of the foreland structural cross section through Santa Cruz. Isostatic compensation from the Andean thrust belt reaches well into western Brazil (from Hortan and DeCelles 1997).

Basement material in eastern Bolivia is comprised of heterogeneous terrane accreted onto southwestern Gondwana during mid Precambrian through early Paleozoic time when it was located in a polar setting (Lindquist 1998). Gondwana, forming the basement underneath Brazil (Brazilian Shield), comprises the earliest geochemically unique section of igneous and related metamorphic rocks forming the Amazon Craton. The Amazon Craton can be divided into four major tectonic provinces that form NW-SE trending belts that decrease in age outwards from the Gondwanan archaean core (Lindquist 1998). From northeast to southwest these provinces are defined as the Ventur-Tapajos (1950-1800 Ma), Rio Negro-Juruena (1800-1550 Ma), Rondonia-San Ignacio (1450-1300 Ma) and Sunsas (1250-1000 Ma) provinces (Lindquist 1998).

The Paleozoic intracontinental Chaco-Tarija basin of Bolivia and Paraguay overlies the suture of the Arequipa massif to the Gondwanan Brazilian shield (Lindquist 1998). Extensive Cambrian-Ordovician rifting resulted in deposition of up to 8 km of marine rocks, influenced by the Precambrian northwest-southeast and northeast-southwest structural trends (Lindquist 1998). During late Ordovician time an
island arc formed off the southern coast of the Chaco-Tarija complex. Rifting persisted through this time, but at a much slower rate.

The Devonian period saw an increase in subsidence as oceanic plate material subducted to the west. This resulted in the deposition of several thousand meters of marine sediments (Lindquist 1998). During Carboniferous time the supercontinent known as Pangea formed. The collision of major tectonic plates resulted in the formation of intracratonic highlands, including the Asuncion arch to the east and the remaining Arequipa massif bordering Chaco-Tarija to the west (Lindquist 1998). Another orogenic event occurred in the Permian period and resulted in deposition, erosion and the development of a marine seaway within Chaco-Tarija.

The late Jurassic Araucanian orogeny marked the opening of the south Atlantic, separating Africa from South America (Lindquist 1998). Erosion of source rocks and Paleozoic sedimentary units accompanied uplift of the southern Michicola arch. Late Cretaceous to late Tertiary, west-to-east propagating thrusts (Andean orogeny) created the Andes Mountains, loading the easterly Chaco plain into a flexural foreland basin and forebulge/backbulge complex that migrated eastwardly through time (Horton and DeCelles, 1997; Dunn and others, 1995). The eastwardly migration of the Andean fold and thrust belt underneath the westernmost section of Chaco-Tarija basin uplifted Paleozoic marine sedimentary packages, which became the source region of Cenozoic sediment cover over much of eastern Bolivia (Figure 6).

2.4 Bolivia’s Notable Ore Deposits

As mentioned earlier the Bolivian tin belt hosts some of the world’s largest Ag and Sn porphyry granite systems. The majority of the ore deposits reside in the southern section of the Bolivian Andes, partially due to the relatively young age of the deposits. There, the shallower erosion levels result in partial preservation of the upper, silver-rich parts of deposits and a number of lithocaps (Sillitoe et al., 1998). Overall, Bolivia contains world’s most unique silver, tin, lead, zinc, gold and antimony deposits.
2.4.1 Cerro Rico

Mineral deposits at Cerro Rico have been of great interest dating back to the Inca Empire. When the Spanish Conquistadores arrived, local Indians and slaves from Africa were put to work to mine the massive silver deposits. It is not known precisely how many people died working in the mines of Cerro Rico during the centuries of Spanish rule. Conservative estimates place the figure at approximately one million people (Boyce, 2004).

The volcanic dome at Cerro Rico hosts the world’s largest silver resource, amounting to at least 2.8 billion ounces of silver prior to colonial exploitation (Sillitoe et al., 1998). In fact Cerro Rico still holds almost five times more silver than any comparable Bolivian deposit. New dating work at the NERC Argon Isotope Facility at the Scottish Universities Environmental Research Center shows that 13.8 million years ago, a dacitic volcanic dome began to form over a shallow magma chamber where two major fault lines in the Earth’s crust met. Studies of minute inclusions of magma preserved in minerals in the volcanic rock show that magmas at Cerro Rico became highly enriched in elements such as silver and tin as it rose through the crust. The overlying dome began to fracture in response to movement along the two major faults as well as an increase in pressure caused by the exsolution of volatiles from a deep magma chamber. When the magma finally cooled at approximately 3-4 km below the surface, hot, aqueous (hydrothermal) fluids enriched in these two metals separated from the magma, and migrated upwards to fill the fractures in the dome and create stockwork ore veins. The veins are more than a few meters in diameter, extend down more than 1 km, and horizontally for 4km. Tin veins generally occur at depth, while the most silver-rich veins are located in the upper levels. Spanish records from the 16th century show that some of these incredible ‘bonanza’ veins contained as much as 40% silver (Boyce, 2004).

The silicified lithocap at Cerro Rico crops out over an area of 1 km² and exceeds 400 m in thickness, much of it hosted by rhyodacite porphyry. The cap hosts disseminated silver mineralization of both hypogene and supergene origin. Argentite, the principal hypogene silver mineral, is converted to acanthite and is associated spatially with disseminated barite (Steele et al., 1996). Other notable minerals
located at Cerro Rico include cryptocrystalline quartz, chalcedonic quartz, tourmaline, dickite, sericite, hypogene aluminum phosphate-sulphate minerals (most notably svanbergite), hypogene pyrite, smectite, chlorite, and alunite.

Figure 7. Arcmap™ image of a few notable Bolivian ore deposits. Tollocci and Cerro Rico are primarily known for hosting large silver deposits while Pacajake host selenium and El Desierto hosts sulfur.

The Miocene tin porphyry systems of Cerro Rico (Figure 7) have a moderately fractionated rhyodacite to dacite bulk rock composition (Dietrich, 2000). Hydrothermal overprint is reflected by strong enrichment of B, Bi, and Sn (>100 times upper crust) and by moderate enrichment of Sb, Pb, Ag, As, Au, and W (10-100 times upper crust) (Dietrich, 2000). Melt inclusions in quartz phenocrysts have been
analyzed by electron and proton microprobe techniques and are characterized by highly fractionated rhyolitic composition with strong depletion of compatible components (0.02-0.14 wt % TiO$_2$, 15-85 ppm Zr) (Dietrich, 2000). The trace element pattern with strong enrichment of incompatible elements (5-17 ppm Ta, 7-85 ppm As, 35-643 ppm B, 20-194 ppm Cs, 13-623 ppm Li, and 5-43 ppm Sn) is similar to tin granite systems (Dietrich, 2000).

2.4.2 El Desierto and Concepcion

The El Desierto mine and the neighboring Concepcion mine (Figure 7) are actively worked sulfur quarries associated with the dormant Cayte volcano, located roughly five miles south of the abandoned village of San Pablo de Napa, at the southern end of the Salar de Empexa (Petrov et al., 2003). Unlike most other Bolivian sulfur mines El Desierto and Concepcion do not reside in the crater of an extinct volcano, but rather on the lower slopes of the Cayte volcano in an old debris avalanche adjacent to Salar de Empexa. The host rock is a Pliocene ash bed approximately 50 to 100 cm thick and covers an area 400m by 2,500m (Petrov et al., 2003). The El Desierto and Concepcion mines are located with the Western Cordillera, which explains the current weak fumarolic activity within the sulfur quarries.

Sulfur, well-crystallized in a wide array of crystal habits ranging from equant to acicular (possibly the habit is dependant on the temperature of deposition) is the most abundant mineral from the two mines and is quite pure, with some of it containing traces of arsenic and selenium (Petrov et al., 2003). The matrix rocks for the sulfur crystals is highly-altered volcanic material consisting now mainly of clay minerals, opal (hyalite), alunite, gypsum and minor films of manganese oxides (Petrov et al., 2003). Kaolinite, mirabilite, alunogen, pickeringite, melanterite and other clay minerals are also present in minor amounts.

When mining commenced in the early 20$^{th}$ century, the sulfur ore at El Desierto was the riches in Bolivia, averaging 80% sulfur (Petrov et al., 2003). Currently approximately 2,000 tons of ore are extracted from the region and transported primarily to Santa Cruz, Argentina, and Brazil. Estimated
reserves are 320,000 tons at 56% sulfur for the El Desierto mine, but other references give a combined reserve for both mines of 500,000 tons at 50% sulfur, and 3,000,000 tons at 33% to 50% sulfur (Petrov et al., 2003).

2.4.3 Tollocci

Tollocci is located within the Bolivian Tin Belt, in the “Los Frailes-Kari Kari” volcanic field approximately 20km WSW of Cerro Rico (Riera et al., 1994) (Figure 7). This volcanic field covers an area approximately 15,000 km² and is primarily composed of ignimbrites and rhyolites of Miocene age. Tollocci resides in a location where the Eastern Cordillera changes from a northwest-southeast direction to a predominantly north-south direction. According to a 1999 Emicruz LTD. report this region hosts a narrow belt with strong northeast-southwest lineaments, perpendicular to the direction of the Andes crosses Tollocci, making this region a structural attraction with good possibilities for mineral exploration.

Previous work in Tollocci by Schneider (1992) describes polymetallic mineralization (Sn, Ag, Zn, Pb, Sb, Bi, U, Au) from “Los Frailes-Kari Kari” volcanic field, related to composite volcanic structures, small calderas, domes of dacitic composition and other volcanic features. Tollocci is one example where Ag-Zn mineral indications are known from Colonial times. EMICRUZ and COMSUR explored this region in the late 1980s and early 1990s looking for the presence of similar ore bodies found at Cerro Rico. Results taken from data acquired from both companies will be revealed later in Chapter 4.

2.4.4 Pacajake

The Pacajake mine, hidden high in the Cordillera Oriental of the Bolivian Andes, is famous for its rare selenides, selenates and selenites, and is the type locality for penroseite (Ni,Co,Cu)Se₂), ahlfeldite (Ni,Co)SeO₃·2(H₂O), olsacherite (Pb₂(SeO₄)(SO₄) and mandarinoite (Fe³⁺₂Se₃O₉·6(H₂O) (Stewart et al.,
It is located on a steep ridge in the Eastern Cordillera approximately 340 km southeast of La Paz (Figure 7). The ore deposit was mined on a small scale from 1922 to 1935 and from 1935 to 1937 for silver and provided geologists with a new mineral called penroseite (Stewart et al., 2003).

The deposit is a vein type and is hosted by dirty white sandstones. It trends northwesterly and dips 60 degrees to the northeast. Old mining logs described the vein as having a gangue of siderite with specular hematite, limonite and small amounts of barite, calcite, pyrite and chalcopyrite (Stewart et al., 2003). Selenides occurred as pockets and eyes in the vein, up to 2 meters long and 25 cm wide, each of which gave 20 to 400 kg of selenides when mined. The selenides included mainly the nickel selenide penroseite, intimately mixed with selenides of lead (clausthalite), silver (naumannite) and mercury (tiemannite) (Stewart et al., 2003). A variety of minor secondary selenates and selenites were also found in the oxide zone. Limonite occurred on all levels, but the selenides were always fresh and unaltered in appearance (Herzenberg and Ahlfeld, 1935; Block and Ahlfeld, 1937).

From 1937 to 1990 the Pacajake mine remained abandoned until a newly discovered vein led to the mine’s reopening. The vein cuts through a major fault in quartzite and white to grey sandstone interbedded with thin siltstones (Stewart et al., 2003). Although the vein has an average width of only 40 cm it has produced disseminated pyrite, chalcopyrite, selenides and limonite. The selenides are dominated by penroseite, clausthalite, tiemannite and naumannite.

2.5 Vegetation

Bolivia contains high rugged mountains, low-lying flat plains, and high plateaus with each landscape affecting the other, geologically, either in terms of sediment erosion/deposition or tectonics. In terms of vegetation, however, each landscape is affected by the other because localized weather patterns and drainage networks. As a result Bolivia contains various vegetation types ranging from high barren mountain peaks to low-lying rainforests (Figure 8).
2.5.1 Eastern Cordillera, Altiplano and Western Cordillera

With an average elevation of almost 4.5 km, western Bolivia resides at elevations much too high to support tree growth. The Altiplano, for example, with an average temperature of 10 °C can reach temperatures as low as -25 °C, making it extremely difficult for large plants to grow. Rainfall, too, in this region is moderate. Due to rain shadow effects caused primarily by the Eastern Cordillera and, to a lesser extent, the Western Cordillera average rainfall in the Altiplano ranges from as little as 20 cm in the extreme southern section to as much as 70 cm in the northern section (Figure 9). As a result of the high altitude and moderate rainfall totals this region is dominated by bunch grass and scattered scrub with vegetation becoming increasingly sparse to nonexistent in the southern region.

The Eastern Cordillera contains a wide variety of vegetation types, primarily determined by elevation and climatic patterns. Predominant regional wind direction in Bolivia is from northeast to southwest. With the Altiplano and Eastern Cordillera in northern Bolivia occupying a much smaller area compared to the south rain shadow effects caused by topography are relatively diminished. As a result more rain falls in northern section of the Eastern Cordillera. La Paz, residing in a valley between mountains receives about 57cm in rainfall per year. Lower elevated regions in the Subandean and Interandean zones achieve high enough temperatures combined with moderate rainfall (between 64 and 76 cm per year) to produce mountain forests. High peaks in this region are annually covered with snow and migrating glaciers.

As mentioned earlier the southern section of the Eastern Cordillera occupies a much greater area, creating a much larger rain shadow to the west despite lower elevations relative to the north. Also, wind patterns do not carry as much moisture into this section of the Andes. As a result rain fall totals are low (~50 cm per year), but greater than the adjacent Altiplano. High mountain peaks are covered by snow and glacial ice. Most of this region is covered by bunch grass, scattered scrub, dry forest, and thorn bush. The extreme eastern section of the Western Cordillera (Subandean and Interandean zones) is covered by mountain forests.
Figure 8. Rudimentary vegetation map of Bolivia showing the various spatial distribution of different vegetation types (from www.lib.utexas.edu/maps/thermic.html).
2.5.2 Eastern Bolivia

Northeastern Bolivia receives the most rainfall of any region in Bolivia. In the northeast the weather is wetter as it is influenced by winds from the Amazon. This region is dominated by tropical
rainforests. The east-central section of Bolivia receives even less rainfall than compared to the north. Much of this region is dominated by grassland, savanna, woodland, palm and riverine forests. To the southeast a much drier climate persists. Open scrub woodlands dominate this region. Overall the elevation of eastern Bolivia ranges from a few tens of meters up to 500m. Local and regional drainage basins forming lukastrine environments produce adjacent marshes. Knowing the generalized vegetation distribution throughout Bolivia helps in the initial stages of analyzing Landsat™ data because it aids in determining what is being viewed.
Chapter 3. Useable Data

Approximately 42 compact discs, provided by EMICRUZ, COMSUR, Sander Geophysics Ltd. and Zonge Engineering, were given to the University of Arizona for phase I analysis. The CD’s contain various geochemical, airborne geophysical, ground geophysical and Landsat™ data. About 50% of the data provided cannot be used for analysis. Some of those files are backup files and, therefore, serve no immediate purpose, while others are duplicate files of other useable files.

Of the unusable files about 20% either could not be used due to errors in the file or limited knowledge of the locations. For example, 53 GXF files contained multiple line errors, which, while opening using Oasis Montaj™, forced the program to abort the operation. The line errors were nothing more than an incorrect symbol, such as a question mark, entered in place of a decimal point. Other GXF, AutoCAD™, ASCII and GRD files contained geophysical data without providing a coordinate system or UTM zone. A coordinate system could be assigned to those files, but without direct knowledge of the UTM zone and border coordinates these files became useless.

Despite the large number of unusable files contained on the CD’s there were also a large number of usable files. The usable file locations are not randomly distributed across Bolivia, but rather, they cover large areas in strategic places where the potential to find profitable ore deposits exist.

3.1 Airborne Geophysical Data

Airborne geophysical data were collected throughout much of Bolivia from as far west as Potosi to as far east as the Bolivia-Brazil border. GXF files, containing ASCII grids, for all survey data was collected for total magnetic intensity reduced (TMI) to the pole and downward continued by 120 m (nT), TMI, terrain elevation, TMI reduced to the pole and upward continued 250m, second vertical derivative of TMI reduced to the pole, first vertical derivative of TMI reduced to the pole, radiometric total counts,
equivalent uranium, equivalent thorium, thorium/potassium ratio, and potassium percentage. When opened using Oasis Montaj the program assigns a RGB scale to it. Each of these files were named either DCT*, UCT*, TER*, TMI*, RTP*, G_*, ANS*, THO*, URA*, POT*, TOPO*, FVD* and SVD*.

Every file contains a 3-digit number in its name to identify its location on a map. For example, the first digit in the file name dct543 qualitatively describes its x-position relative to the other dct* files in the same UTM zone. A first digital of 5 means that particular file is located west of other dct* files beginning with 6, 7, 8 or 9 and east of file beginning with the digits 0, 1, 2, 3 or 4. Relative location can also be determined using the last two digits. The last two digits qualitatively describe the files’ y-position on a map for a given area such as Las Petas. A number of 43 means that dct* file is located to the south of other dct* files containing numbers greater than 43 and north of files with numbers less than 43. Based on the 3-digit number of a particular file the location can be determined, relatively, compared to other files with the same prefix. Overall, there are approximately 487 GXF files with 434 of those containing no line errors. Each individual file contained information about the proper UTM zone to use when displaying the data in a defined projection system.

GRD files contain the same type of information as the GXF files, but without the possibility of line errors. As a result all GRD files are candidates for usage. However, one drawback to these files is that the files do not contain information about the UTM zone in which they were created. Many files came without READ.ME files describing their proper UTM zone. Also, some GRD files, when created, did not contain coordinates. When opened using Oasis Montaj arbitrary numbers were assigned to individual points on the image relative to the origin (0, 0). Despite the limitations of the GRD files overall there are approximately 539 usable files.

Of the 973 total usable GRD and GXF files only approximately 65-70% was used for geophysical analysis. The reasons for such a low percentage are due to data collector and producer organization. First, multiple CD’s contained identical files such as ter543.GRD. Second, most GRD files were produced from GXF files and in some cases the GRD files were accompanied by the original GXF files. In the end only about 600-650 GRD and GXF were processed for geophysical analysis. In other words some files were redundant.
3.2 Ground-Based Geophysical Data

Ground-based geophysical data arrived in a variety of formats such as ASC and WQ1. There are approximately 300 ground-based geophysical files on all the CD’s, but only 24 of those files were used in geophysical analysis. A number of factors contributed to the low percentage of useable files. First, many of the files did not come with a READ.ME file describing the proper UTM zone. This contributed to losing about 50% of the files. Second, about 25% of the unusable files did not have labels in the header. Each of those files contained a large quantity of data, but whoever produced them did not provide information describing the nature of the numbers. Lastly, the remaining 25% were duplicate files of other unusable data, primarily of the files containing no header information.

The 24 files that were deemed usable covered significant portions of Bolivia’s land area. Each file is named either MAG*, SPEC*, COMP*, T1-MAG*, T2-MAG*, T1-256, T2-256 and REM* and contains information that can be opened in a spreadsheet. MAG files contain numerical data for UTMX, UTMY, MSLZ, RAD, RAWMAG, MAGDCOR, MAGIGRFC, LEVMAG, TOPO, DATE and TIME. SPEC files contain numerical data for UTMX, UTMY, MSLZ, RAD, BA, COSMIC, TOTRW, KRAW, URAW, THRAW, UP, TOTFIN, KFIN, UFIN, THFIN, DATE, TIME. T1- and T2-MAG files contain numerical data LONGL, LATL, FLT, DAT, TIME, LONGD, LATD, ALTD, EAST19S, NORTH19S, MAGRAW, DC-MAG, IGRF, MAGIGRF, DIURNAL, DIURNALF, RADALT, BARALT, EFFHGT, TEMP. T1- and T2-256 files contain numerical data LONGL, LATL, FLT, DAT, TIME, LONGD, LATD, ALTD, ALT, EAST19S, NORTH19S, TOTRAW, KRAW, URAW, THRAW, COSMIC, UPRAW, RADON, RADALT, EFFHGT, BARALT and TEMP.

The last of the geophysical data came in the file format DWG. These files are AutoCAD files and are extremely useful. Of the 55 DWG files about 30 were used for interpretation. The 25 unusable files were deemed useless either because they contained irrelevant data (a single unidentified block) or lacked a defined coordinate system. Of the 30 useable files 27 were maps that displayed lineaments, geologic units,
geochemical data and production mines. The remaining three usable files were geologic cross sections that could be used for interpretation only and could not be projected onto a map.

3.3 Geochemical Data

There exists a large amount of geochemical data dispersed throughout the southern two-thirds of Bolivia. Unfortunately not all of the data could be processed for analysis. Of the approximately 60 files about 56 were deemed usable. However, unlike the unusable geophysical data, most of the unused geochemical data has potential to be used later (phase II of the project). Only a few large files contained northing and easting coordinates, making it a time consuming process to locate the proper coordinates and UTM zone for the rest of the files.

Of the 56 useable files only 18 were used for the analysis of soil and surface rock samples, partly due to the redundancy of data. The soil and surface rock samples were split up into three folders called Potosi, La Paz and Santa Cruz on the Data B250 Bolivia cd. File names were assigned to the region which the majority of the samples originated. Within each folder were folders called drill and geoquim, referring to either surface rock data or drill data. Within each folder were files called analysis.dbf, samples.dbf and labres.dbf. The three .dbf files contain the majority of the geochemical information such as assay data, location data and sample data.

The completed geochemical files followed a particular naming convention. Each study area was named and the rock samples within that particular area were assigned that location name. Most the geochemical files contain assays for metals and other elements relative to the deposit type. The rest of the files contain combinations of various chemical species (concentration or percentage) such as Au, Ag, Pb, Zn, Cu, Bi, As, Ba, Bi, Sb, Hg, Mo, Ni, Co, Cd, Fe, Mn, Te, Cr, V, W, Sn, La, Al, Mg, Ca, Na, K, Sr, Y, Sc, Ga, Li, Nb, Ta, Ti and Zr. Other data contained within some geochemical files include drill_from, drill_to, method (for analysis), geologist, remarks, project code, analytical suit, analytical type, sample type, location name, province, elevation, sample date and air photo.
3.4 Satellite Imagery

There exist ten Landsat™ images of Bolivia. Of the ten images provided six are usable, three are duplicates and one displays only one band. Two of the usable files are located over the southern section of the Eastern Cordillera (CD files 232-74, 231-74) in the Potosi region and the remaining four are located in eastern Bolivia (227-73, 228-73, 229-74 and 232-71). Each ERS file contains a combination of the following bands 1 (0.45-0.52 μm), 2 (0.52-0.6 μm), 3 (0.63-0.69 μm), 4 (0.76-0.9 μm), 5 (1.55-1.75 μm), 6 (10.4-12.5 μm) and 7 (2.08-2.35 μm).
Chapter 4. Processing

A significant amount of processing took place in an effort to ensure not only quality control, but to create images and to analyze geophysical and geochemical data. Attention to detail is vital in mineral exploration so properly displaying and analyzing data are keys to success.

4.1 GXF and GRD Data

GXF and GRD files contain similar data and, as a result, are processed in practically the same way. Each usable file contains coordinates within the image as well as a color grid displaying units. Hence, the only processing taking place includes conversion to IMG files so they can be displaying in Arcmap™. The exception to the previous statement includes GXF files with line errors that need to be fixed.

In Oasis Montaj™ the first step in processing GXF and GRD files is to convert each file to its own GeoTIFF. This is accomplished by clicking menu Grid → Copy/convert grids. A box opens that allows you to select the input grid file and the output grid file. By clicking on the browse button opposite the input grid file one can search for the file of interest that needs to be converted. Then clicking the browse button opposite the output grid file one can choose the file type to convert the GXF or GRD file to (GeoTIFF). GRD files will not contain any line errors so by clicking the okay button the GRD file becomes properly converted to a GeoTIFF file. If line errors occur within a particular GXF file and error message will pop up telling you the location (line) of the error. Of course, not all GXF files contain line errors and some contain multiple line errors. The quickest way to locate the line-containing error is to open it with excel. If say, the error occurred at line 23,945 then, in Excel™, you can go directly to that line and correct the mistake. In general the mistake is a typo such as a symbol in place of a decimal point or a negative sign. Once correct, step one in Oasis Montaj™ can be repeated for that particular GXF. If no other line errors occur then the
file will successfully be converted to a GeoTIFF. If more line errors occur later in the file another error message will pop up and inform you of the mistake. Unfortunately Oasis Montaj will convert GXF files from start to end. As a result it can only catch one error at a time. So if multiple line errors occur, then step one may be repeated numerous times.

Once converted to a GeoTIFF the next step will be to go to menu Grid → Re-project a grid. The GeoTIFF must now be converted to an ER Mapper™ file. Click the browse button across from grid file. This will allow the user to select the GeoTIFF to be converted. After pressing the next button another window opens displaying grid name, length units, projection, type, lat0, lon0, SF, FE, FN, datum, ellipsoid, major, eccen, primsmer, local datum transform, and warped. The user must specify the correct datum and projection for the coordinates attached to the file. After clicking modify a dropdown menu will allow the user to select the coordinate system. For these files the proper selection will be projected (x,y). After clicking next again, the proper datum and projection methods must be chosen from respective dropdown menus. WGS 84 is used for datum and the specified UTM zone (found in most READ.ME files) is either zone 19S, 20S, or 21S. After selecting the correct attributes the user must click the back button twice. This brings the user back to the modify box. Each cell should now contain all relevant information to properly display the file. After selecting okay a new box appears that allows the user to select new projected grid file. The best choice to select is the ER Mapper™ file (color). This will allow the file to maintain color, although significant degradation may occur.

GeoTIFF files must be converted to ER Mapper™ files because Erdas Imagine™ cannot process GRD, GXF or GeoTIFF files with the proper assigned coordinates. After converting to GeoTIFF the next step is to go to menu Import. A box opens that allows the user to select import or export. Once selecting importing the proper file type (GeoTIFF) must be selected using the dropdown menu bar across from type. Next the correct media type (file) must be selected using the next dropdown box across from media. By clicking the open folder icon across from input file the user can choose an ER Mapper™ file that needs to be converted to an IMG file. The program automatically gives output file the same name as the input file and attaches the file extension .img. After clicking the okay button a new window opens. This window
simply lets the user know the input file, output file, rows, columns, bands and x and y locations of the file. By clicking on the okay button the ER Mapper™ file is converted to an IMG file.

The next step is to click menu DataPrep → reproject images. For some reason when converting the ER Mapper™ files to IMG files the projection assigned to the file in Oasis Montaj™ is lost. The coordinates are still attached to the file, so the user must simply reproject the image again, this time in Erdas Imagine™. By clicking the open folder icon adjacent to the input file the user can select an image to be reprojected. The user must then assign the new output file a different name. Under categories the user must select, from the dropdown menu, the proper datum (UTM WGS 84 South). Under projecting the user must select, from the dropdown menu, the correct projection (UTM zone 19, 20 or 21). The user can then choose resampling methods, polynomial approximation, rigorous transformation, tolerance and maximum poly order. Considering degradation of the colors occurs after using Oasis Montaj™ the rest of the selections matter only minutely. Hence, the goal is to accurately display each grid in Arcmap™, but make interpretations in Oasis Montaj™.

Now each IMG file can be opened and displayed in Arcmap™. In Arcmap™ the user simply has to click on the yellow plus sign in the menu bar to locate the files to be imported. Once an image is selected and the add button from the pop up widow has been pressed the image will appear on the screen in the exact location it was derived. Some images contain extra white strips that need to be eradicated from the display. By right clicking IMG file in the display box and selecting properties a new window opens. Within this window select the symbology tab. By checking the display background value box and changing the zeros to 255 the user can choose how the white strips will be displayed. By selecting the no color option within the adjacent dropdown box and clicking the okay button the white strips disappear.

4.2 AutoCAD™ data

The program AutoCAD™ specializes in the generation and analysis of drawing files or DWG files. Similar to GXF and GRD files DWG files contain coordinates within and image. The major
difference between DWG and GRD and GXF files is that DWG files can contain qualitative data and quantitative data. GRD and GXF files can only contain quantitative representations. As a result DWG files can be projected and interpreted in Arcmap™.

DWG files must also be converted into different file types in order to be imported into Arcmap™. The first step is to display a DWG file in AutoCAD™ by clicking menu file → open. Within the new window the user can select a DWG file of interest for conversion. Once the file is displayed in the viewer screen it must be saved as a different file type by clicking menu file → save as. In the dropdown menu of the file of type select AutoCAD™ R12/LT2 DXF. This format produces the least amount of file degradation even though it deteriorates the file significantly.

The next step is to open Oasis Montaj™ and click menu Map → import → AutoCAD™ DXF file. Simply click the browse button and locate the DXF file to be imported. After clicking the okay button a new window opens which is the same window for copying/converted GXF and GRD files. The same selections for GXF and GRD should be made for DXF files. When the user has reached the projected coordinate system (x,y) window and clicks the okay button a window pops up that contains the DXF coordinate systems. Simply click next to reach the next window. The new window will give the user the options of changing the name of the new map that is being created. When the user clicks the finish button the new map is displayed.

After creating a new map the user must click menu Map → export. A window appears that allows the user to select the output file format from the first dropdown menu bar. The proper file type to select is ER Mapper™ RGB. Under the image resolution section the user has the option of changing the resolution. When the proper resolution parameters have been chosen click the okay button. Now the file has successfully been converted to an ER Mapper™ file and the user can follow the steps mentioned about for processing and reprojecting ER Mapper™ and IMG files using Erdas Imagine™ and Arcmap™.
4.3 Geochemical Data

A total of 18 files were used for geochemical processing. Those 18 files were located in folders based on their location and samples type (surface data or drill data). For example within the Potosi folder on the Data B250 Bolivia cd there were two subfolder named drill and geoquim. The drill folder corresponded to drill data and the geoquim folder corresponded to soil and surface rock data. Within the drill or geoquim folder were three files called analysis.dbf, samples.dbf and labres.dbf. These files contain almost all of the useable geochemical data for that particular region. In the geoquim folder the same three files exist, but contained different data relevant to the soil, surface rock and region of the main Potosi folder. The same holds true for the La Paz and Santa Cruz folders.

Within each geoquim folders of Potosi, La Paz and Santa Cruz are rock samples descriptions. Alteration (mineral data included), rock type and structural information exists in three separate files named rxaltmin.dbf, rxdescri.dbf and rxstruct.dbf respectively. For each region the geochemical data had to be joined with the geological data in order to ensure all the rock data was available for use. Using Arcmap™ a join function was first used between the samples.dbf and analysis.dbf files based on sample id. From there another join could be made using the labres.dbf file based on lab id. Once the geochemical files were joined the resulting file contained sample id, location, coordinates and geochemical data etc. The resulting geochemical file was then joined, individually, with the three geologic files (rxaltmin.dbf, rxdescri.dbf and rxstruct.dbf). Six files were joined into one large file for each of the three regions.

Much of the geochemical data came from rock chip sampling, but select drill hole and soil data was also available. All three joined files (La Paz, Potosi and Santa Cruz) were individually exported, using Arcmap™ as text files and analyzed in Excel™. The text files still in Arcmap™ were converted to shape files for data manipulation to be used in conjunction with the newly exported text files. By clicking menu geostatistical analysis → geostatistical wizard a specific interval shape file can be added as dataset 1 in the upper left corner of the window. Using the subsequent dropdown menu the user can choose the chemical species of interest for analysis. For the validation dataset the user can choose the associated text file. In
the subsequent dropdown menus the user must choose the same chemical species as in dataset 1 and the easting and northing coordinates. The geostatistical wizards gives the user the opportunity to select a method in which the data will be analyzed such as inverse distance weighting (IDW), global polynomial interpolation, local polynomial interpolation, radial basis functions, kriging and cokriging. Kriging was selected for all geochemical data.

After clicking the next button the program takes the user to another screen. Here, the operator has the choice of selecting certain parameters such as method of sampling, neighbors to include, shape type, angle, major semiaxis, minor semiaxis, test location and preview type. The method chosen for all geochemical data is neighborhood and the number of neighbors to include depends on the number of data points. After clicking the finish button the new kriged surface appears on the map. However this method will not accurately portray the chemical species distribution at a given drill level if it is known that the samples came from vein deposits. This method can only work if samples are taken from some larger igneous body such as a pluton or sill.

4.3 Landsat™ Data

There are six usable Landsat™ data files (Figure 10). These images arrived in the file format ER Mapper™ and had to be converted to IMG files in order to import them into Arcmap™ and to create ratio maps and structural maps in Erdas Imagine™. Converting the ER Mapper™ files to IMG is discussed earlier in this chapter.

Ratio maps are created by clicking menu Interpreter → Spectral Enhancement → Indicies. While in the Indicies window the user can only create one predefined ratio image. First the user must choose the input file in which the ratio map will be derived from and name the subsequent output file. For all the images the sensor and data type outputs must be Landsat™ and unsigned 8 bit. The last step involves choosing a ratio in which the user is interested. The available choices include NDVI, IR/R, SQRT(IR/R), Vegetation Index, TNDVI, Iron Oxide, Clay Minerals, Ferrous Minerals, Mineral Composite and
Hydrothermal Composite. Files 227_73_I7.img, 228row73.img, 232row71.img and 229_74.img are located in eastern Bolivia (with the exception of 229_74.img which is located in northern Paraguay) where much of the land surface is covered by various vegetation types. Therefore the functions NDVI, Vegetation Index and Clay Minerals were selected for these files within Indicies. The other two files, 231_74.img and tm232_74_051186.img, are located in the Altiplano and Eastern Cordillera and, therefore, contain far less vegetation spread across the surface. As a result, the functions NDVI, Vegetation Index, Clay Minerals and Mineral Composite were used in Indicies.

Figure 10. Arcmap™ image displaying locations of six useable Landsat™ images.

Structural maps were created by selecting menu Interpreter → Spatial Enhancement → Convolution. In the Convolution window the user must choose the input file of interest to use and name the subsequent output file. For the kernel type there exist 30 distinctly different functions the user may
choose. For all the Landsat$^{\text{TM}}$ images the filters 5X5 Horizontal, 7X7 Horizontal, 5X5 Vertical and 7X7 Vertical were used to enhance any structural trends.

### 4.4 Magnetic and Spectral Data

Most of the magnetic and spectral ASCII files were very large (up to 400,000 kb). The data were not added to each file in regularly spaced intervals and resulted in the inability to directly import into Arcmap$^{\text{TM}}$. As a result the files had to be opened in Excel$^{\text{TM}}$ as tab delimited in order to gain regular spacing. However, Excel$^{\text{TM}}$ can only hold approximately 7,000 kb of data and most magnetic and spectral ASCII data is greater than 10,000 kb.

First each ASCII file had to be opened in textpad, because it displays the number of highlighted lines. Approximately 64,000 highlighted lines could be copied and pasted into a notepad document (this is the upper limit data size excel can handle). After saving the file as T1-SPEC-1 for example (the original file name in which this section of data was derived is called T1-SPEC) it could then be opened as tab delimited in excel. By doing so each column is equally spaced and, therefore, importable into Arcmap$^{\text{TM}}$. Considering the large number of other data (geochemical, Landsat$^{\text{TM}}$, and other geophysical) available the processing of the magnetic and spectral ASCII files is of the lowest priority partially due to time constraints. However, these data will likely be completely processed before the completion of phase II.

For the small amount of magnetic and spectral ASCII data that were processed geostatistical analysis was used to create IDW surfaces (described in chapter 3.3 for various geophysical attributes (Observed Chargeability for example) included in each file. Due to the large amount of point data creating IDW surfaces files not only were time consuming but took up vast quantities of memory.
Chapter 5. Interpretation

Interpretations from this chapter are based on the results from processing of geochemical data, geophysical data and Landsat™ images. Interpretations have been made that not only aid in understanding identified potential ore deposits, but also in understanding the geology and everything that affects the geological environment. Vegetation interpretations have been made in order to understand the vegetation type, growth and vigor. Vegetation may yield clues as to the nature of the soil and rock type beneath. Further analysis of the Landsat™ imagery may complement the geological finds from the rest of the data.

The remaining data have been interpreted for the purpose of discovering or developing potential ore deposits where applicable. All interpretations are subject to the limitations of the available data sets and limited knowledge of specific geological environments and may be viewed as generalization.

5.1 Geochemical Data

Properly used geochemical data plays a vital role in detecting ore bodies. Certain concentrations of elements from all types of geochemical data sources (soil, outcrop, stream, float, top of bedrock and drill holes) give indications to the presence of an ore body. Even without the aid of geophysics the determination of whether an ore body exists can be made with only a geochemical sampling of the area of interest. The first step in finding an ore body using geochemistry involves testing soils and outcrops.

Soils are generally tested for a variety of different elements. Some elements such as the economic ones themselves (Au, Ag, Pb etc.) may suggest the presence of each element in economic proportions nearby. Other elements such as As and Hg used as pathfinder elements. Detection of high levels of As may indicate the presence of economic Au while high levels of Sb may indicate the presence of and Ag-Zn-Pb ore body. Initial outcrop data from the same area can used in conjunction with soil data. If soil data indicates high levels of Bi for example, then nearby outcrops should also contain high Ag levels (assuming
no displacement has occurred). If both soil and outcrop data agree then more outcrop sampling and drilling may ensue. Stream data may also be used for determining if a prospective area exists upstream.

If a particular area displays signs of economic potential then drilling ensues and is based upon soil and outcrop findings. Geostatistics and spatial distributions of element concentrations locate zones of high potential. These zones are then drilled and analyzed geochemically. For an area to be mined it has to be economical to extract the material of interest. Sufficient drilling of a location can be used in the determination of the extent of an ore body. If the ore body is of sufficient size and of significant grade then geophysical surveying can ensue and will aid in determining its probable economic output.

Geochemical data from this project were collected over a wide range of locations from within a few hundred kilometers of the Bolivia-Chile border to as far-east as to within about 500 kilometers of the Bolivia-Brazil border. With such a small percentage of Bolivia’s mineral potential exploited the probability of finding the remaining economic mineral bodies is greater than in other better explored countries.

5.1.1 Soil, Outcrop and Drill Sampling

Soil sampling is generally conducted on a grid system either rectangular in shape or squared with sample spacing ranging between 15-60 meters for follow-up surveys and between 300-1500 meters for reconnaissance surveys. Sample spacing for all data within the dataset ranges from 100 meters to over 1000 meters. In general, most of the soil geochemical sampling in the data set is considered reconnaissance. However surveying is conducted based upon the field geologist’s perception of what the underlying lithology is. If the geologist believes and area to be of great economic interest despite no previous work being done in the area, then he or she may still set sample spacing at less than 100 meters.

Sampling of soil takes place in any combinations of varying soil horizons. Each soil horizon, in general, will yield different values for the same element of interest. In mountainous terrain (Bolivian Andes) depth to the first soil horizon may be less than 15 cm. Rock hammers and shovels can effectively
remove overburden to expose soil horizons. In regions where soil is located at deeper depths or are considered stony soils augers, percussion drills or diamond drills may be used. For the dataset soil horizons information was absent.

Unlike soil surveys outcrop sampling is not conducted on a grid system. First, rocks may not outcrop in such a way to conduct sampling on a grid system. Second, analysis of outcrop data differs from soil analysis. Outcrops are not subject to dispersion or secondary element mobility and, as a result, must be analyzed individually, separate from other samples and other geostatistical methods (e.g. averaging effects).

Each rock unit also may contain various grain sizes, primary dispersion patterns and chemical/textural heterogeneities. When sampling an outcrop it is imperative to collect a sample size in accordance to typical grain size. In a primarily fine-grained rock it is generally sufficient to collect a sample weighing 500 grams while sampling of a pegmatite may require a sample weight of 5000 grams. Sampling must also occur within the upper portion of the outcrop, excluding weathered surfaces. Collecting a sample 10 centimeters within an outcrop will minimize weathering effects. Shallow drilling of less than one meter generally accomplishes the task.

Outcrop sampling of a target area must exceed the area of interest. By doing so background samples can be identified, meaning the extent of the surficial target (ore body) is covered. This may include extending sampling across fault zones and alteration zones. Including alteration and rock type information in conjunction with geochemical data is critical in defining the lithology and type of ore body encountered. However some of the rock samples in this dataset do not include alteration or rock type information. While basing statements off of geochemical information alone lacks concreteness and relegates it to intense conjecture it still provides the most crucial information towards finding ore deposits. After all without knowing concentrations of elements locked up within rocks it becomes impossible to calculate ore grade and to even determine if an area is minable.

Drill core sampling generally occurs within an area thought to contain economic potential. Drill cores, soil, drill chips and outcrops samples may be geochemically analyzed using atomic absorption (AA) and/or inductively coupled polarization (ICP). The weight of the sample must be known prior to analysis.
Drill cores and drill chips are collected from small region within the ground, generally in 2-3 meter depth increments.

Figure 11. Arcmap™ image of Bolivia. Yellow dots represent rock or soil sample locations.

Several of the geochemical files are located in or around the Bolivian Tin Belt in the Eastern Cordillera. Previous sampling within this zone by various mining companies and independents (since colonial times) have detected moderate to high levels of Au, Ag, Sb, As, Cu, Pb, Zn, Sn and Bi. Geochemical sampling within and around the Bolivian Tin Belt has occurred recently by companies as a result of its economic potential. Other areas of geochemical sampling have occurred within the Altiplano
and Western Cordillera due to its geologically recent volcanism. Prominent volcanic features with surficial alteration zones have been recognized (Cachi Laguna) and subjected to minor erosion due its young age.

Eastern Bolivia (plains) hosts multiple major suture zones between Precambrian terrains coupled with ancient volcanic regions. Suture zones provide a major avenue for transporting ore fluids. Older known ore bodies (compared to the Bolivian Andes) within eastern Bolivia are rich in Au, Fe, Pb and Zn, making the plains prospective.

Considering what little amount of economic mineral extraction has occurred in Bolivia coupled with known economic geochemical provinces makes it highly prospective. Determining the geochemical makeup of various regions within Bolivia will aid in defining more economic geochemical zones and lead to a better understanding of Bolivian ore deposits. The locations described in this section were deemed to have the best potential of all the properties found within the dataset.

5.1.2 Tollocci

Tollocci, a 10 Ma caldera, was first mined by the Spanish at nearly the same time as Cerro Rico (approximately 500-700 years ago). It has remained an ideal location for prospecting in more recent times partly because of its location in the eastern half of the Los Frailes-Kari Kari volcanic field and partly because of its lithological units. Tollocci is located within the Bolivian Tin Belt and its rock units correlate well with other areas of known Ag-Sn-Zn mineralization (Cerro Rico, Porco and Chachacomiri). Since the time the Spanish first mined Tollocci geological knowledge and mining techniques have improved drastically to find and mine ore. As a result many areas within Tollocci still posses significant Ag-Sn-Zn mineralization that the Spanish either had no knowledge of or could not mine using their older techniques.

Tollocci geology is composed of fresh rhyolite, diatreme breccia, sanidine dacite, intracaldera breccia, tuffaceous rhyolite, felsic porphyrytic rocks and some undifferentiated sedimentary units (Figure 12). A mixture of intrusive, subvolcanic and volcanic rocks comprises the generic origin of the igneous rocks on the property. Most of the dacitic rocks exposed at the surface contain a porphyritic texture. In
other areas tuffaceous units dominate the landscape and represent one of several volcanic episodes of the region. Several calderas remnants litter the area and are filled with intracaldera breccias.

Figure 12. Arcmap™ (background taken from Google Earth™) image of Tollocci geology. Surface and drill indicated Ag mineralization is highlighted in yellow. White lines indicate resistivity lines. The orange line corresponds with a zone of high resistivity (silicification).

Alteration at Tollocci is dominated by two styles that include silicification and argillization. Both alteration styles play a vital role in mineralization in area. Iron oxides are abundant on the surface and stain, to some degree, all units exposed. Sericite alteration has been identified on primarily the dacitic rocks where plagioclase is relatively abundant. Evidence of leaching exists on the property leaving vuggy material behind. Remobilization of Ag has likely occurred to some degree. Pyrite has also been identified at the surface, but is rare.
The available dataset included 257 rocks samples and 22 drill holes. Approximately 31 holes were drilled of which only 22 contained eastings, northings, assays and geology. Only Ag, Pb and Zn were available for analysis. Table 1 lists significant drill intercepts for Ag and Zn.

<table>
<thead>
<tr>
<th>Hole ID</th>
<th>Ag</th>
<th>Ag</th>
<th>Zn</th>
<th>Zn</th>
<th>Zn</th>
</tr>
</thead>
<tbody>
<tr>
<td>EAT001</td>
<td>30m @ 102.5 ppm</td>
<td>6m @ 47.9 ppm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EAT002</td>
<td></td>
<td></td>
<td>2m @ 0.60%</td>
<td></td>
<td>7m @ 0.43%</td>
</tr>
<tr>
<td>EAT003</td>
<td>12m @ 42.0 ppm</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EAT006</td>
<td>20m @ 136.2 ppm</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EAT007</td>
<td>5m @ 29.0 ppm</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EAT008</td>
<td></td>
<td></td>
<td></td>
<td>65m @ 0.44%</td>
<td></td>
</tr>
<tr>
<td>EAT009</td>
<td>12m @ 119.9 ppm</td>
<td>18m @ 34.4 ppm</td>
<td>4m @ 0.88%</td>
<td>16m @ 1.12%</td>
<td>7m @ 0.68%</td>
</tr>
<tr>
<td>EAT010</td>
<td></td>
<td></td>
<td>46m @ 1.04%</td>
<td></td>
<td>15m @ 0.31%</td>
</tr>
<tr>
<td>EAT011</td>
<td>6m @ 33.0 ppm</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EAT012</td>
<td>36m @ 15.8 ppm</td>
<td></td>
<td>20m @ 1.22%</td>
<td></td>
<td>8m @ 0.84%</td>
</tr>
<tr>
<td>EAT014</td>
<td>2m @ 25.4 ppm</td>
<td>6m @ 15.4 ppm</td>
<td>14m @ 0.43%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EAT015</td>
<td>2m @ 54.9 ppm</td>
<td></td>
<td>104m @ 0.67%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EAT016</td>
<td>34m @ 35.0 ppm</td>
<td>2m @ 17.1 ppm</td>
<td>20m @ 0.45%</td>
<td>3m @ 0.78%</td>
<td></td>
</tr>
<tr>
<td>TDH002</td>
<td>3m @ 54.0 ppm</td>
<td></td>
<td>36m @ 1.08%</td>
<td>53m @ 0.44%</td>
<td>5m @ 0.87%</td>
</tr>
<tr>
<td>TDH003</td>
<td>2m @ 30.4 ppm</td>
<td></td>
<td>8m @ 0.61%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TDH004</td>
<td>2m @ 51.6 ppm</td>
<td>228m @ 79.2 ppm</td>
<td>18m @ 33.4 ppm</td>
<td>9m @ 33.6 ppm</td>
<td>32m @ 0.41%</td>
</tr>
<tr>
<td>TDH005</td>
<td></td>
<td></td>
<td>37m @ 0.24%</td>
<td>2m @ 0.65%</td>
<td>33m @ 0.43%</td>
</tr>
<tr>
<td>TDH006</td>
<td>18m @ 14.1 ppm</td>
<td></td>
<td>27m @ 0.25%</td>
<td>16m @ 0.32%</td>
<td>64m @ 0.35%</td>
</tr>
</tbody>
</table>

*Table 1. Table of significant Ag and Zn drill intercepts.*

Much of the Ag mineralization is hosted within silicified material. Silicified tuff and breccia account for the majority of Ag mineralization. The higher Ag grades are contained within the cores of silicified bodies that can generally contain more than 5% pyrite. Here, Ag can reach values of up to 400
ppm. Moving outwardly from the silicified core the Ag grades tend to decrease. However, Ag can still reach values of over 100 ppm where silicification is persistent. The silicified bodies are almost always surrounding by argillized material. When Ag mineralization is present at the silicified/argillized boundary Ag generally drops from a few tens of ppm to less than one ppm, indicating a hard boundary exists between the two alteration styles. However, Ag mineralization can be found in the argillized rocks close to the silicified/argillized boundary where the transition between the two alteration styles is gradual.

**Figure 13.** Arcmap™ (background taken from Google Earth™) image of Zn mineralization indicated by surface sampling or drilling.

Unlike Ag, Zn is mostly found within argillized rocks. Zn mineralization, in general, is widespread, but lacks in overall grade. Most of the significant Zn intercepts are below 1.0%. Figure 13 is a map of the Tollocci area displaying a potentially continuous zone of Zn mineralization. The breccia body
drilled into by holes EAT10, EAT009 and EAT016 define a zone of best Zn potential. In EAT10 and EAT009 Zn grades reach up to almost 3.0%.

Emicruz has provided preliminary reserve estimates for Ag in Tollocci based on the 31 drill holes. The largest ore body with good Ag values is Juchuy Tollocci, which has been drilled into by holes EAT001 and TDH006. It contains at least 2.5 Mt @ 139 ppm Ag and this figure could potentially increase to 5.6 Mt @ 133 ppm Ag with further exploration. Comsur calculated a reserve value for another silicified body, Manto Español, at approximately 619,000 tons @ 169 ppm Ag. Other Mantos ore bodies and veins were calculated by COMSUR, giving a total of 1.4 Mt @ 139 ppm Ag (including Manto Español) in positive plus probable reserves. The epithermal system could therefore contain a volume higher than 7 Mt @ 134 ppm Ag.

Tollocci is a good Ag prospect and minor Zn prospect, although little sampling, drilling and geophysical work has been done between holes EAT010 and EAT008. Further analysis of this area should provide greater insight into not only the extent of the Zn anomalous zone, but provide greater knowledge of Ag values in the adjacent area. Ag has good potential in the Juchuy Tollocci area. High resistivity and minor drilling have identified an area of moderate to high Ag contained within strongly silicified rocks. Further infill drilling is recommended in order to further define the Ag mineralization.

5.1.3 Povenir

Povenir is located approximately 11.5 km N-NE of Avicaya and 26 km E of Lake Poopo. 91 rocks samples were collected covering and area approximately equal to 12 km². Similar to Avicaya the local rocks are comprised lower Paleozoic planar laminated siltstones and massive bedded sandstones (Figure 14). The closest igneous rocks to Povenir reside over 10 km away on the fringe of Avicaya.

Most of the rocks at Povenir are fractured to a certain degree. High angle faults cut the clastic rocks and dip anywhere from 64° to 90°. It is likely the faults are genetically related to the observed fractures and tend to strike in similar directions. The strike direction of the faults and fractures averages
around 90º E, but gradually changes from the south to the north. At the southern end of the property high angle faults and fractures strike between 90º and 110º SE. To the north the structures rotate towards true north, varying between 40º and 70º NE.

Figure 14. Arcmap™ image of Povenir geology. Green crosses = vein locations.

Alteration at Povenir is dominated by oxidation. Much of the oxidation occurs along fractures in the rock, but can also occur along bedding. Sericitic alteration is generally weak throughout the area and likely resulted from the alteration of feldspars within siltstones and impure sandstones. Silicification has also been observed, but is primarily restricted to the SW section of the property where massive bedded sandstones have been converted to quartzite. Lastly, chlorite altered rock has been observed, but is a rare occurrence.
Despite the fact that igneous rocks reside many kilometers away from Povenir quartz veining exists on the property. The outcropping quartz veins are likely epithermal and are of the high sulfidation polymetallic type. The veins contain a mixture of oxide and sulfide material, indicating the oxide portion is not very extensive. Although major vein occurrences are relatively infrequent they do contain significant amounts of metals. For example grades of up the 447 ppm Ag, 1.0 % Pb (over limit), 15.0% Zn (over limit), 0.096% Cu, 0.071% Sn, 0.16% Cd and 0.27% As have been reported. Ag consistently occurs at moderate to high grades within the veins while Zn is typically high grade. Other than pyrite the only other sulfide mineral identified from the quartz veins is sphalerite. Because of the close association between Ag and Zn in the veins, sphalerite is likely to be argentiferous.

Unlike quartz veins the clastic rocks contain only sporadic mineralization, although high grade Ag (501 ppm) and Zn (15.0%, over limit) have been reported. Elevated Pb, Cu, Sn, Cd, As and Sb values have also been reported, but are generally more sporadic on the property than Ag and Zn. High metal grades within the clastic rocks likely occur along fractures within the rock. Some of the faults on the property are also mineralized, although only to a moderate degree, and probably served as conduits for ascending metal-bearing fluids.

Povenir has moderate small scale mining potential. Ag and Zn are the most economically important metals on the property. The few quartz veins that have been sampled contain high grade Zn along with moderate to high grade Ag on argentiferous sphalerite. Although the clastic rocks contain sporadic mineralization they typically are unmineralized. Future work must focus on developing an understanding of vein density, vein length, average grade, vein orientation etc. in order to determine if Ag and Zn can be economically extracted from quartz veins at Povenir. Avicaya, to the southeast, contains similar rock units to Povenir, with the exception of the existence of minor igneous units at Avicaya. Nevertheless it is possible that mineralization at Povenir and Avicaya are linked to the same hydrothermal system with Povenir representing the more distal portion of that system. Almost no exploration work has been conducted within the region sitting between Povenir and Avicaya however. Future work is also recommended here to further the understanding of both Povenir and Avicaya. Lastly, geophysical
surveying is recommended to determine if a large buried intrusion exists in the region that may be responsible for mineralization.

5.1.4 Colavi

Colavi is located approximately 35 km NE from the city of Potosi in the Eastern Cordillera of Bolivia. It resides to the east of the Las Frailes volcanic field by up to a few tens of kilometers. Similar to other sections of the Eastern Cordillera, Ordovician and Silurian sediments dominate the landscape (Figure 15). Igneous rocks also exist throughout the area in the form of Tertiary felsic to intermediate volcanics. Colavi has been known to miners for quite a while as small scale mining has taken place in the past within and around the Colavi area.

The three main alteration types found in the area include oxidation, argillization and silicification. Image 232_74_051186 (Figure 16) displays an alteration composite of a portion of the Altiplano and Eastern Cordillera. The Colavi area is outlined in yellow. Much of the area outlined contains the color purple, which signifies a mixture of clay minerals and iron oxide material. Of the 446 available rock samples the vast majority show argillic and/or oxide alteration, which is consistent with the composited alteration image.

Much of the rocks in the Colavi area are cut by faults and quartz veins. The area contains faults of varying orientation, which likely accounts for the 43 quartz vein samples containing varying orientations. Quartz veining is abundant throughout the area and cuts the Ordovician-Silurian sedimentary rocks as well as the Tertiary volcanic rocks. It is likely that the quartz veining is genetically related to the Tertiary volcanic rocks.
Figure 15. Arcmap™ image of the geology of Colavi.
The quartz veins are of the polymetallic type, containing anomalous quantities of Ag, Pb, Zn, Cu, Sn, Bi, As, Sb, Fe and Mn. However grades are not consistent and vary widely from one vein sample to another. For example, Cu ranges from about 0.005% to 3.5% and Ag ranges from 0.2 ppm to 501 ppm. Such variations in grade may be the result of either selective sampling or irregular grade distributions within the mineralized and non-mineralized veins.

Most of the polymetallic veins are only moderately to weakly oxidized. In fact the majority of the metals are contained within sulfides and not oxide minerals. Some of the sulfide species logged include pyrite, galena, cassiterite and sphalerite.
Figure 17. Arcmap™ image of the mineralized zones at Colavi.

Figure 17 shows the distribution of quartz veins in relation to surface geology. Veining appears to cut all rock types, implying it is younger than all the exposed rocks. Much of the high grade Ag occurs either within or in close proximity to quartz veins. The high grade Ag that is found in close proximity to the veins is primarily hosted in sandstone. Much of the abundant Ag is found where the sandstone is
heavily oxidized with or without any silicification. The sandstone beds were likely porous enough to allow hydrothermal fluids to pass through them and deposit Ag, while the volcanic units likely lack the necessary porosity. The lone exception may be the porphyritic rocks where sporadic high grade Ag, Pb and Zn have been reported.

Future work in the Colavi area should include surface mapping of the veins and faults. Quartz veining may, in fact, follow the orientations of various fault zones. The polymetallic veins contain the highest metal grades and should be located as well as mapped, particularly within the sandstone beds. Potential dissemination into the sandstone units opens up the possibility for finding near surface high tonnage ore.

### 5.1.5 Santa Catalina

Santa Catalina is located less than 8 km east of the Chilean border and 73 km NW of Lake Coipasa. 249 rocks samples were taken from the mountains surrounding Santa Catalina Loma. The property (~95 km$^2$) is dominated by igneous rocks such as granodiorite, dacite, diorite, andesite and rhyolite that reside within close proximity to the strike length of the Chilean copper belt to the west (Figure 18). The only sedimentary rocks present are igneous related volcaniclastic sediments that originated from the surrounding hills and mountains.

Much of the igneous material on the property display porphyrytic textures and are likely to be genetically related. The small differences in composition may have resulted from some degree of fractional crystallization. But most likely similar, but varying degrees of crustal assimilation affected multiple intrusion episodes in the area. The intrusive and extrusive rocks reside near the eastern edge of the volcanically active western cordillera and are Tertiary (Miocene to Pliocene) in age.

Much of the granodiorite material is brecciated and likely formed in response to surrounding magma movement and/or exsolution of the volatile elements. The diorite material is also brecciated, but to a much lesser extent than the granodiorite. It is possible that the less evolved diorite unit intruded the
granodiorite and is, therefore, younger. Breccias within the diorite and granodiorite units may have also formed in response to widespread faulting. Much of the faults display normal offset, which may represent surface manifestations of the magma cooling process. However, the dominate fault trend direction is north, which may indicate faulting occurred along regional preexisting zones of weakness in the crust.

Figure 18. Arcmap™ image of the geology of Santa Catalina.

Alteration at Santa Catalina is widespread and includes multiple alteration styles at varying degrees. Silicification and argillization are the two most dominant alteration styles on the property. Propylitic and Sericitic alteration are also present, but not widespread or pervasive on the property. Much of the surface is oxidized to some degree and is locally intense in certain areas. Much of the brecciated areas contain a mixture of oxides and sulfides unlike the non-brecciated rock.
The youngest alteration feature present at Santa Catalina is quartz veining. Veining is widespread and abundant throughout the property. Unlike faults in the area the veins do not generally trend one direction. Rather the vein’s strike lengths range anywhere from due north to due east. Most of the sampled veins contain no significant metal content. However, low to moderate grades of certain metals have been reported that include Au (up to 0.258 ppm), Ag (up to 514 ppm), Pb (up to 9.3%), Zn (up to 0.26%), Cu (up to 4.0%) and Mo (up to 0.48%).

Similar to the quartz veins the surrounding igneous rocks contain virtually no significant metal content. The igneous rocks, while highly altered between successive quartz veins, contain only minor fracturing. While porphyry textures are abundant throughout the igneous units it is possible the Santa Catalina hydrothermal system did not fully develop into a prototypical economic porphyry Cu deposit. The abundance of quartz veining, however, suggests that metaliferous fluids were able to separate from the magma and migrate to the surface. The combination of abundant quartz veining and porphyry textures on the property indicates a porphyry system did develop at Santa Catalina.

Overall Santa Catalina is not a good porphyry Cu prospect, but nevertheless, still possesses some potential. High temperature alteration minerals such as biotite are relatively absent at the surface, while cooler, more distal propylitic alteration is scattered throughout the property (it is possible the propylitic alteration is the product of retrograde alteration). Perhaps a higher grade primary chalcopyrite core exists to the hydrothermal system that gives little indication of its presence at the surface. A few drill holes placed properly could test this possibility and either confirm or deny further exploration potential.

5.1.6 San Florencio

San Florencio is located on the border between the states of Potosi and Oruro, approximately 4 km SW of the town of Chiquilla. Approximately 753 rock samples were collected over an area approximately equal to 6.7 km². San Florencio resides in the eastern cordillera of the Bolivian Andes and is dominated by clastic sedimentary rocks (Figure 19). Massively bedded sandstones comprise the majority of the clastic
rocks in the area, but massively bedded siltstone, planar laminated sandstone, planar laminated siltstone and convoluted greywacke (soft sediment deformation?) have also been identified.

![Figure 19. Arcmap™ image of the geology of San Florencio.](image)

Although sedimentary rocks dominate the landscape at San Florencio igneous rocks have been identified from rock chip sampling. Most of the igneous rocks are compositionally equivalent to rhyolite or dacite and occur as either volcanic (tuffaceous) or subvolcanic in mode. Much of the rhyolites have been fractured, while the dacitic rocks are relatively intact. Minor outcrops of hydrothermal breccias and ignimbrites have also been identified.

Alteration at San Florencio is dominated by argillization. With the exception of rhyolites every rock type on the property has been argillized to some degree, possibly indicating the rhyolitic unit is post
mineral in age. Feldspathic sandstones have been argillized at sites within the rock matrix containing either plagioclase or orthoclase. Oxidation, silicification and sericite alteration also exist on the property, but are much less abundant than argillic alteration. Sericite has replaced much of the feldspars in the feldspathic clastic rocks where argillic alteration has been relatively weak or absent. In the rhyolite unit sericite alteration is rare and is absent in the dacite unit. Silicification is primarily restricted to the clastic units, but is sparse in occurrence. Oxidation occurs in all of the rock units at San Florencio, but primarily occurs within the clastic rocks.

Based on surface rock sampling anomalous Au, Ag, Pb, Zn and Sn mineralization has been identified within the altered areas of San Florencio. Metal contents reach grades of up to 0.75 ppm Au, 201 ppm Ag, 1.0% Pb (over limit), 1.0% Zn (over limit) and 17.4% Sn. Although Au and Zn mineralization have been identified, surface sampling generally revealed only sparse anomalies. Ag, Pb and Sn mineralization, on the other hand, are widespread and abundant. Much of the moderate to high metal grades are hosted by the massively bedded sandstone. While some mineralization occurs within the igneous rocks, the dacite and rhyolite rocks are generally unmineralized and may represent a late stage, post mineral subvolcanic to volcanic event.

The massively bedded sandstone rocks are typically sporadically fractured throughout the area. In places where the fracture density is high metal content generally increases. The highly fractured sandstones are concentrated within a spherical zone that is cut by normal faults and is adjacent to dacite and rhyolite outcrops. This zone contains moderate to high grade Sn ranging from approximately 0.1% to over 2.2% within the sandstone host rock and 0.52% to 0.81% within the normal faults (Figure 20). Ag mineralization is also present within the Sn zone, but tends not to occur as high grade.

The Sn zone varies, in terms of alteration, from the rest of the property. While much of the property is dominated by argillization the fracture zone is dominated by silicification and moderate to high temperature sericite. The fact that Sn mineralization is found within the highly fractured sandstone zone that exhibits distinct alteration relative to the rest of the property indicates that Sn formed within a structurally and mineralogically unique setting. In terms of exploration these characteristics should be taken into account when assessing potential Sn targets.
Adjacent to the Sn zone is an extensive area of argillized sandstone. In contrast to the sandstone within the Sn zone the argillized sandstone contains only minor silicification with widespread Ag and Pb mineralization. Ag and Pb are generally low grade but can reach grades of up to 201 ppm and 1.0% (over limit) respectfully. Au mineralization is also present, but extremely sparse.
A total of seven holes were drilled in 1997 within San Florencio, but contained no log data. Figure 20 displays the collar locations and the approximate 2D orientation of the drill holes. Each drill hole was drilled to the southwest and none were drilled through the surface indicated Sn zone. However, significant Zn mineralization was encountered to the west of the Sn zone that includes 247 meters of 1.12% Zn (Table 2). A total of four drill holes hit extensive Zn mineralization adjacent to the Sn zone. All of the moderate to high grade Zn was encountered at a distance of at least 100m down the hole (all the holes were drilled at approximately 60°). Coupled with the fact that the Zn grades at the collar were generally below 100 ppm explains the reason for the lack of surface indicated Zn mineralization based on rock chip sampling.

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<td>76m @ 0.23%</td>
<td>247m @ 1.12%</td>
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<tr>
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<td>179m @ 1.07%</td>
<td>42m @ 0.13%</td>
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<td>-</td>
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<td>164m @ 0.40%</td>
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<tr>
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<td>-</td>
<td>184m @ 0.69%</td>
<td>-</td>
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<tr>
<td>ESF005</td>
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<td>16m @ 0.48%</td>
<td>12m @ 0.69%</td>
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<tr>
<td>ESF007</td>
<td>30m @ 31.7 ppm</td>
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</tr>
</tbody>
</table>

**Table 2.** Table of significant Ag, Pb, Zn and Sn drill intercepts.

Low Ag and minor Pb grades were also encountered by the drilling. Low to moderate Ag grade extents all the way from ESF002 to ESF007, which may indicate the presence of a broad area of mineralization. Pb was also encountered over a broad area, but the lacked any sort of spatial continuity. Ag and Pb mineralization occur together and are probably mineralogically related. It is likely that, if sulfides exist at depth, galena is argentiferous.

Overall San Florencio has good mineral potential. The surface indicated Sn zone contains an average of 0.62% Sn that locally reaches grades of up to 2.26%. No drilling has occurred in this region leaving the possibility for future exploration work. A resistivity survey is recommended to determine the
areas of high resistivity that may correspond to a high degree of silicification. The silicified rocks in the Sn zone contain the higher grades.

The other major exploration target resides off the west of the Sn zone. Moderate Zn grades occur of large intervals and were encountered by all of the drilling in the north. This area has the potential to be a large Zn based on the drilling. Infill drilling will need to occur in order to better define the broad zone of Zn mineralization. It is possible that Zn occurs in highly argillized rocks. A resistively survey is recommended in order to determine areas of intense argillization and open spaced breccias zones. Ag also occurs in the same vicinity as Zn and the low grades could make the Zn target more economically attractive.

5.1.7 Cerro Turqui

Cerro Turqui is 5,150 meter high mountain located approximately 27 km NE of Cerro Rico. It is thought to not only be located along the same geological trend as Cerro Rico, but also to contain similar formations. Cerro Turqui has been worked on a small scale in the past for metals such as Sn, Bi, Ag and Sb. A total of 156 rock samples have been collected from the flanks of the mountain down to the neighboring streams covering an area approximately equal to 25 km².

The geology of Cerro Turqui consists of a mixture of clastic sedimentary rocks and intermediate igneous rocks (Figure 21). The peak and western flank of Cerro Turqui is dominated by a brecciated diorite unit. To the north a small area of porphyritic diorite is exposed. The clastic rocks at Cerro Turqui are composed of dark Paleozoic shales and scattered outcrops of sandstone. Quartz veining is present and widespread throughout the area.

Alteration of the rocks on the property varies considerably in terms of style. Evidence of silicified, oxidized, chloritized, sericitized, pyritized, argillic and advanced argillic alteration have all been identified through rock chip sampling. However silicification is the most pervasive and affects the clastic units as well the igneous units. The second most pervasive alteration type is oxidation. Image
232_74_051186 from Figure 22 confirms the rock chip sampling alteration. The white box indicates the approximate location of Cerro Turqui. According to the ratio the image this area should contain widespread oxidation. The turquoise color consists of a mixture of the green and blue bands which represents iron minerals and iron oxide minerals respectively.

Figure 21. Arcmap™ image of the geology of Cerro Turqui.
Quartz veining is the most important geological feature identified at Cerro Turqui. Grades of up to 5.47 ppm Au, 137.5 ppm Ag, 1.0% Pb (over limit), 15.0% Zn, 974.8 ppm Cd, 0.2% Bi (over limit), 1.0% As (over limit) and 0.2% Bi (over limit) have been reported in the veins. The veins cut the Paleozoic clastic rocks as well as the intermediate intrusive rocks. The quartz veins are likely genetically related to the diorites on the property and formed during a late stage mineralizing event as the intrusive diorites cooled.

Figure 22. Landsat™ ratio image of image 232_74_051186.
Much of the clastic and igneous rocks exposed at the surface are brecciated to some degree. About one-third of the breccias in the diorite unit are hydrothermal breccias. The hydrothermal breccias likely formed from a later injection of magma into the magma chamber. As cooling began in the magma chamber a new injection of magma caused the water-rich diorite to hydrofracture. Brecciation in the surrounding clastic rocks was likely due to the same event. Here brecciation formed in response to the intrusion of magma by breaking to make room for new material.

The brecciation event structurally prepared the surrounding clastic and igneous rocks for later mineralization by creating a fluid pathway for metal-bearing solutions to travel through and saturate. Much of the mineralizing fluids deposited metals within breccia matricies or within quartz veins. The aqueous solutions contained high grade Bi, As, Sb and Ag along with moderate amounts of Au, Pb and Zn. Some of the identified hypogene minerals include asenopyrite, bismuthinite, cassiterite, galena and argentiferous galena.

Cerro Turqui is a good prospect for Ag, Bi, As and Sb. The hydrothermal system deposited these metals within quartz veins and breccias in clastic rocks and intrusive diorites. The widespread brecciation and pervasive oxidation (leachability) on the property makes Cerro Turqui an attractive property for small or large scale mining. Further rock sampling and mapping is needed to identify the extent of brecciation on the property at the surficial level. Little indication of vein orientation exists, so further mapping is needed to also determine the strike length, dip and grade continuity.

5.1.8 Omoxa

Omoxa is located approximately 100 km northwest of Lake Poopo in the Eastern Cordillera. 355 rock samples comprised of sandstone, siltstone, dacite, quartzite, breccia, and fault breccia were available for analysis. Rock chip sampling occurred over an area just greater than 2,600 km².
Figure 23 shows the generalized geologic map of the area. The northern section of omoxa is primarily composed of sandstone and quartzite, while the southern section is a mixture of dacitic igneous rocks and sandstone. Where exposed the sandstone is primarily planar laminated with occasional outcrops of massive bedding. To the southeast the sandstone is primarily massively bedded. This massively bedded unit transitions into a planar laminated sandstone and low grade quartzite to the northwest.

Figure 23. Arcmap™ image of the geology of Omoxa.
The general strike direction of the sedimentary beds ranges from approximately 300° to 330° NW. This is perpendicular to the direction of thrusting in the Eastern Cordillera of central Bolivia. Faulting and fracturing, however, vary much more in terms of strike direction, but appear to be dominated by two primary strike directions; 30° NE and 290° NW. With two primary fault and fracture strike directions roughly perpendicular to one another the potential for intersecting faults appears to be high. Intersecting faults coupled with significant alteration in the area makes omoxa an interesting target for exploration.

Much of the rock exposed at the surface is oxidized with the scarce appearance of hypogene pyrite. Oxidation generally occurs along fractures in the rock. Silicification and oxidation appear to be the major alteration products in the area, although significant areas of argillic, sericitic and chloritic alteration exist. Quartz veining is also present on the property, although it is not a common feature. Much of the veining occurs as veinlets in the rocks no greater than a few centimeters in diameter.

Despite the widespread alteration much of the rocks chips contained low to moderate values for Au, Ag, Pb, Zn, Cu, Sn, W, Co, Cd, Ni, As, Bi and Sb. However, samples of moderately to strongly silicified fault breccia contained high grade Au ranging from 4.2 to 21.3 ppm and moderate Ag values ranging from 0.6 to 148 ppm. Most of the fault breccia rock samples were taken from normal faults, indicating a relatively young age (post thrusting) of mineralization. Samples adjacent to the highly mineralized fault areas contained little to no Au and Ag, indicating a lack of dissemination. The two exposed leached zones (Figure 23) contain a few samples of moderate Au and Ag grades however, but lack overall spatial continuity. Based on the spatial distribution of Au and Ag it appears likely that the surrounding quartzite, sandstone, siltstone and dacite rocks may be poor host rocks.

Despite the likelihood for poor host rocks in the area, omoxa is still a good exploration target. The high grade Au and moderate Ag, Bi, As and Sb originating from fault breccias indicate ore fluids were moving through and depositing metals along these fault controlled breccia zones. Although little to no mineralization exists in the rocks surrounding the mineralized faults there still exist the possibility of fracture controlled mineralization at depth. If no significant mineralization exists at depth in the surrounding rocks, the surface indicated high grade oxide Au in the faults could still be mined and heap leached without the added cost of building and operating a sulfide processing facility.
More surface mapping and sampling is needed to better define the extent of Au and Ag grades contained within the fault breccias. Soil sampling is also recommended to determine where metals have bled out of mineralized structures. If drilling commenced perpendicular to the strike of these faults, then it may yield a better three-dimensional picture of the geology and mineralization.

5.1.9 Cachi Laguna

Located in the extreme southwestern portion of Bolivia, Cachi Laguna resides in Western Cordillera. Previous studies by Emicruz have identified a volcanic center called the Cachi Laguna volcanic complex that contains mineral potential. A total of 2,907 outcrop samples, 82 drill and 902 soil samples were taken from various locations within and surrounding the volcanic complex. Cachi Laguna is a strato volcano composed of felsic to intermediate igneous rocks. The three main rock types include latite, andesite and intermediate porphyry (Figure 28).

Two soil grids were created over the volcanic complex, each with an east-west spacing of 25 m and a north-south spacing of 100 m. The southern soil grid covers an area primarily composed of andesitic rocks, while the northern grid covers an area composed of a mixture of porphyritic rock and felsic latites. It appears likely that the two soils grids represent two distinct populations, although the number of low Au and Ag values in each population is too great to separate completely. For simplicity the two soil grids were combined upon analysis.

Upon analysis of the soil data a few positive correlations coefficients were calculated. Au correlates well with Ag, Bi and Sb with values of 0.546, 0.633 and 0.521 respectively. Ag correlates well with Au, Pb, Bi and Sb with values of 0.546, 0.343, 0.491 and 0.921 respectively. Anomalous values (> 2 standard deviations) were reported for Au, Ag, Pb, Bi, As and Sb as values reached as high as 0.867 ppm, 51 ppm, 0.74%, 0.2% (over limit), 0.2% (over limit) and 0.1% (over limit) respectively. Interpolation of Au and Ag were created based on the encouraging soil data analysis.
Figure 24. Arcmap® (Google Earth™ image in background) surface map of ordinary kriged Ag (based on soil data). Kriged surface covers an area approximately equal to 2.8 km². Major range = 592.663, anisotropy direction = 344.7°, partial sill = 29.414, total sill = 40.859, nugget = 11.445, lag size = 50 m and number of lags = 12.
Figure 25. Arcmap™ (Google Earth™ image in background) surface map of ordinary kriged Au (based on soil data). Major range = 494.051, anisotropy direction = 348.5°, partial sill = 0.0014116, total sill = 0.003467, nugget = 0.0020553, lag size = 50 m and number of lags = 12.

Figure 24 displays an ordinary kriged surface of the combined soil grids for Ag in ppm. The nugget value equals approximately 28% of the total sill and the major range is slightly less than 600 meters.
Despite the fact that the nugget is relatively high the range of spatial correlation is relatively long. A long range suggests that Ag estimates made beyond 592.663 meters of the closest soil sample are beyond the range of correlation. The Root-mean-square standardized value approximately equals 1.018, meaning the kriging surface slightly overestimated the Ag values at the known locations. The color display range, taken from the quantile break values produced from the soil data, shows show high Ag values in red and low values in blue. Values range from as low as 0.1 ppm to as high as 51 ppm. Based on the anisotropy direction produced by ordinary kriging (344.7º) the large Ag anomaly runs NW to SE.

Ordinary kriged Au (Figure 25) shows a similar anisotropy direction (348.5º) and major range (494.051 m) as Ag. However, the nugget value of the kriged Au surface is greater than that of the kriged Ag surface and approximately equals 40% of the total sill. Unlike Ag the Au anomaly is much less pronounced and continuous to the north. However, the southern extent of the Au surface shows a moderate anomaly. Overall the strength of the Au anomalies is weaker than the Ag anomalies. Regardless Au shows a positive correlation with Ag at 0.546. Both Ag and Au show positive correlations with Bi and Sb (Au:Bi = 0.633, Ag:Bi = 0.491, Au:Sb = 0.521, Ag:Sb = 0.921).

Rock sampling of the volcanic complex covered the entire extent of the soil grid as well as minor portions of the volcano’s flanks and surrounding stream channels (Figure 26 and Figure 27). Dirt roads were carved into the landscape that cut across the heart of the volcano. From the road wall rock samples were taken approximately one meter from the next in the direction of the road in order to produce ample sampling density. Surface sampling indicates shallow Ag and Au mineralization in the porphyritic rocks and latites.

Surface alteration is dominated by argillization and silicification (Figure 29). However several other types of alteration and alteration features exist throughout the volcanic complex that includes propylitic, quartz veining, leaching, argillic, advanced argillic and pyritization. Cachi Laguna exhibits a typical alteration zonation pattern consistent with high sulphidation epithermal deposits. At the center alteration consists of a core comprised of vuggy quartz and transitions outward to a quartz-alunite zone, illite-kaolinite zone, chlorite zone and finally into unaltered rock.
The most important alteration types associated with Ag and Au mineralization include silicification and adjacent vuggy silicification. Leaching of the rocks occurs when highly acidic magmatic gasses dissolve the minerals in the surrounding rock (primarily feldspars), leaving a quartz-rich, vuggy textured mass behind. These vuggy areas appear to trend in the same direction as faulting (~ 90° E). Faults likely provided a good pathway for ascending gasses and ascending/descending fluids to travel through.

Figure 26. Arcmap™ (Google Earth™ image in background) surface sampling map of Ag grades.
High grade Au, Sb and Bi are abundant throughout the leached zones (Au up to 30.1 ppm, Sb up to 1.89% and Bi up to 0.196%) while the highest Ag, Sb and Bi grades can be found in highly silicified rocks (Ag up to 1.3%, Sb up to 9.9% and Bi up to 2.95%). Ag grades in the leached zones remain high
(reaching up to 277.5 ppm) but do not attain the anomalous levels of the surrounding silicified rocks. Au, on the other hand, is abundant throughout the leached zones and strongly silicified zones. Therefore, Au remained immobile during the leaching process while some Ag became remobilized and was redeposited.

Dickite also plays an important role in Au and Ag mineralization. In general moderate Au and Ag grades can be found in close proximity to dickite alteration. The best grades associated with dickite occur where the rock has been silicified. Au and Ag grades can reach up to 2.5 ppm and 695.1 ppm respectively.

Figure 28. Arcmap™ (Google Earth™ image in background) image of the geology of Cachi Laguna.
Similarly to Au and Ag, high grade Pb can be found in association with dickite and silicification. Grades of up to 4.5% Pb can be found in rocks containing dickite alteration in association with silicification. High levels of As can also be found in silicified rocks and reach grades of up to 1.64%.
Unlike Ag only a few good Zn grades were found at the surface. The majority of Zn mineralization occurs in argillized rocks and reaches grades of up to 2.76%.

A total of 82 holes were drilled by Emicruz over two drill campaigns within the Cachi Laguna volcanic complex. The first drill campaign, which began in 1994 and ended in 1995, consisted of 21 moderate to deep holes beginning with the prefix DDH. These holes targeted high grade large tonnage ore bodies extending well into the subsurface and were angled anywhere from 60° to 90° with respect to the horizontal. Much of the Au and Ag mineralization failed to extent to deeper levels. Instead much of the Au and Ag grades discovered by the first round of drilling extended to no more than 50 to 100 m depth.

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<td>28</td>
<td>131.1</td>
<td>16</td>
<td>0.74</td>
<td>28</td>
</tr>
<tr>
<td>CLR15</td>
<td>1.90</td>
<td>14</td>
<td></td>
<td></td>
<td>0.42</td>
<td>40</td>
</tr>
<tr>
<td>CLR16</td>
<td>1.36</td>
<td>20</td>
<td></td>
<td></td>
<td>1.76</td>
<td>20</td>
</tr>
<tr>
<td>CLR20</td>
<td>66.4</td>
<td>48</td>
<td></td>
<td></td>
<td>0.45</td>
<td>48</td>
</tr>
<tr>
<td>CLR23</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.35</td>
<td>26</td>
</tr>
<tr>
<td>CLR25</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.76</td>
<td>28</td>
</tr>
<tr>
<td>CLR29</td>
<td>2.62</td>
<td>10</td>
<td>76.0</td>
<td>28</td>
<td>0.30</td>
<td>22</td>
</tr>
<tr>
<td>CLR38</td>
<td></td>
<td></td>
<td>113.3</td>
<td>34</td>
<td>0.47</td>
<td>36</td>
</tr>
<tr>
<td>CLR43</td>
<td></td>
<td></td>
<td>312.8</td>
<td>12</td>
<td>1.14</td>
<td>8</td>
</tr>
<tr>
<td>CLR44</td>
<td>0.95</td>
<td>72</td>
<td>45.4</td>
<td>60</td>
<td>0.40</td>
<td>14</td>
</tr>
<tr>
<td>CLR46</td>
<td>2.72</td>
<td>10</td>
<td>186.9</td>
<td>34</td>
<td>0.31</td>
<td>32</td>
</tr>
<tr>
<td>CLR50</td>
<td></td>
<td></td>
<td>512.0</td>
<td>18</td>
<td>0.30</td>
<td>10</td>
</tr>
<tr>
<td>CLR52</td>
<td>0.37</td>
<td>28</td>
<td>166.2</td>
<td>60</td>
<td>0.29</td>
<td>60</td>
</tr>
<tr>
<td>CLR60</td>
<td></td>
<td></td>
<td>84.1</td>
<td>32</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CLR8</td>
<td>1.63</td>
<td>8</td>
<td>157.2</td>
<td>16</td>
<td>1.00</td>
<td>12</td>
</tr>
<tr>
<td>DDH002</td>
<td>4.90</td>
<td>11</td>
<td>107.5</td>
<td>9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DDH003</td>
<td>5.00</td>
<td>12</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DDH004</td>
<td>0.54</td>
<td>40</td>
<td>56.6</td>
<td>21</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DDH009</td>
<td></td>
<td></td>
<td>62.7</td>
<td>111</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DDH019</td>
<td>0.58</td>
<td>29</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DDH020</td>
<td>0.48</td>
<td>39</td>
<td>100.5</td>
<td>51</td>
<td>0.31</td>
<td>25</td>
</tr>
<tr>
<td>DDH021</td>
<td>1.09</td>
<td>16</td>
<td>87.5</td>
<td>89</td>
<td>0.68</td>
<td>30</td>
</tr>
</tbody>
</table>

Table 3. Table of significant Au, Ag and Sb drill intercepts.
The second round of drilling began in 1996 (with the prefix CLR) and targeted shallow high grade Au/Ag mineralization. Table 3 shows several round 1 and round 2 significant drill intercepts. Many of the CLR holes encountered Au and Ag mineralization as well as high grade Sb reaching up to 13.01%.

A three-dimensional block model was created to define a potential resource for the Cachi Laguna deposit. Approximately 30% of the surface samples and 74% of the drill holes did not contain any geologic information. As a result the model was designed, geologically, based on the available geologic information. Surface samples and drill holes that contained no original geologic information were assigned geologic codes based on their relative location to drill holes and surface samples with geologic information.

Drill holes were composited to a fixed length of 10 meters to match the 10 x 10 x 10 meter block dimensions. However geologic breaks in the compositing run were made when different rock types were encountered. As a result some composites contained lengths of less than 10 meters. Due to time constraints the surface samples were not converted into horizontal drill holes. Instead each sample was considered a separate pseudo drill hole with a composite length of 1.0 meter.

Statistics were calculated using the composites for rock type, alteration and a combination of rock type and alteration. Alteration appeared to have the greatest effect on grade distribution for Au, Ag, Pb and Sb. Rock type mattered slightly only when separating out the porphyrytic unit. Variography was then performed on the composite data, separately for each alteration style and for the porphyrytic unit. Due to time constraints global variograms were created instead of directional variograms.

Ordinary Kriging was used for interpolation of Au and Ag blocks. Au and Ag displayed high variability between adjacent samples (high nugget). Therefore, a cap was placed on outlier samples of 32 ppm and 500 ppm for Au and Ag respectively. An outlier cutoff distance of 10 meters was used for Au and Ag. In total six mineralized Au and Ag zones were defined. Table 4 (all Au and Ag grades were converted to opt) lists the statistics for Au and Ag based on surface and drill indicated. Drill indicated/inferred refers to all blocks that contain a grade greater than 1.0 oz/t for Ag or 0.01oz/t for Au (mutually exclusive), are greater than 30 meters below the current surface and contain a pass number anywhere from 1 to 4 (Table 5). Surface differs from drill indicated/inferred only by the criteria that it is less than 30 m below the current surface.
Table 4. Table final block model results for Au and Ag.

<table>
<thead>
<tr>
<th></th>
<th>Drill Indicated/Inferred Au oz</th>
<th>Drill Indicated/Inferred Ag oz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface Indicated/Inferred Au oz</td>
<td>102,833</td>
<td>25,133,615</td>
</tr>
<tr>
<td>Surface Indicated/Inferred Ag oz</td>
<td>5,840</td>
<td>3,534,673</td>
</tr>
<tr>
<td>Total Au oz</td>
<td>108,673</td>
<td>28,668,288</td>
</tr>
<tr>
<td>Total Ag oz</td>
<td>300,125</td>
<td>1,158,850</td>
</tr>
<tr>
<td>Mean Surface Grade (ppm)</td>
<td>0.5528</td>
<td>86.65</td>
</tr>
<tr>
<td>Drill Tons</td>
<td>7,295,000</td>
<td>11,297,500</td>
</tr>
<tr>
<td>Mean Drill Grade (ppm)</td>
<td>0.4005</td>
<td>63.20</td>
</tr>
<tr>
<td>Total Tons</td>
<td>7,595,125</td>
<td>12,456,350</td>
</tr>
<tr>
<td>Total Average Grade (ppm)</td>
<td>0.4123</td>
<td>67.26</td>
</tr>
</tbody>
</table>

Table 5. Table of criteria used in order to establish a pass number for any given block.

<table>
<thead>
<tr>
<th>Pass</th>
<th>number of drill holes used</th>
<th>average distance to composites</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pass 1</td>
<td>4 to 8</td>
<td>0.1 to 25.0 meters</td>
</tr>
<tr>
<td>Pass 2</td>
<td>4 to 8</td>
<td>25.1 to 50.0 meters</td>
</tr>
<tr>
<td>Pass 3</td>
<td>4 to 8</td>
<td>50.1 to 100.0 meters</td>
</tr>
<tr>
<td>Pass 4</td>
<td>1 to 3</td>
<td>0.1 to 100.0 meters</td>
</tr>
</tbody>
</table>

Based on the block stats the mean Au and Ag surface grades are greater than the mean grades at depth. In fact approximately 50 to 100 meters below the surface Au and Ag values diminish greatly to uneconomic grades. Hence the best grades reside at or near the surface. Supergene processes may have played a role in enriching near surface rocks with Ag. On the other hand silicification, which is the primary alteration type to host Ag and Au, diminishes in intensity at depth. Variation in dominant alteration styles and intensity may have also played a key role in enriching the strongly silicified surface rocks compared to rocks at depth.

Cachi Laguna has good economic potential for Au, Ag and Sb. Mean Au, Ag and Sb grades are not high, but can locally exceed 215 ppm, 1.35% and 13.01% respectively. High grade Au is primarily contained within the leached rocks at the surface and can reach grades in excess of 1.0 opt. Ag high grade, on the other hand, is primarily contained within near surface strongly silicified porphyrytic rocks, but can also reach values of up to 277 ppm in leached zones. The leaching of some Ag at the surface may account
for some of the difference in grade between the leached and silicified zones. Similar to Ag, high grade Sb is contained within strongly silicified porphyritic rocks. However, high grade Sb is also present in the leached zones, indicating Sb may have remained immobile during the leaching process. Sb correlates well with Ag, as well as Bi, in the strongly silicified rocks and, in the hypogene zone, where leaching of Ag has not occurred, argentiferous (Bi-bearing) stibnite and bismuthinite comprise the majority of significant ore minerals of Ag and Sb. Acanthite, Ag-bearing halides and native Ag comprise the main supergene Ag ore minerals.

In terms of general mining costs high surface Au, Ag and Sb grades help to reduce stripping ratios, although near surface hypogene mineralization is present, which can substantially increase production costs and recovery. However, in places such as the Zed Williams area within the Bald Mountain mining district in Nevada, acid soluble auriferous bismuthinite yields up to 99% recoverable Au. Therefore, it may be possible to heap leach oxide Au and auriferous bismuthinite zones. Further acid soluble tests will be required to potentially implement this idea.

With high grade Ag at the surface attached to (argentiferous) stibnite, the possibility for high grade Ag at depth exists. In fact a few deep Ag and Au zones were penetrated by drilling. Considering relatively few drill holes penetrated depths beyond 100 m, significant deep Ag and Au targets have not been adequately defined. More infill drilling is recommended to better determine Ag grades at the surface and at depth. Resistivity surveying is also recommended in order to better identify areas of strong silicification.

5.1.10 La Recuperada

In the western section of the Eastern Cordillera resides a mixture of rock and soil samples from the area known as La Recuperada. A total of 1,738 samples were collected covering an area approximately equal to 76 km². Of those samples 869 are soils. The soil samples were collected based on a grid system (Figure 30). Grid spacing in the NW-SE direction is 50 meters, while the spacing in the NE-SW direction
is 100 meters. 36 elements were assayed in all and elements such as Sn, W, Sc, Nb, Ta, Ti, Au, Cd, Bi and Sb reported values below detection.

The elements Ag, Pb, Zn, Cu and As were checked for evidence of multiple populations. However, it was concluded that only one population of soil data exists. The most important elements to the soils study area are listed in Table 6. Ag, Pb and As obtain high maximum values, but are also highly skewed to the right (Figure 31). The highly skewed elements have distributions that are close to being lognormal, while those elements such as Zn and Cu have distributions closer to normal. Assuming no erroneous assays were reported the reason for Ag, Pb and As showing highly skewed distributions (another way to view highly skewed data is one standard deviation >> mean) arises from the significant number of anomalous values existing in the data set. For example, Pb has a mean of 120 ppm, but a maximum of 3316 ppm, which is approximately 27.6 times the mean. Such high values will pull the mean away from the median and closer to the high end.

<table>
<thead>
<tr>
<th></th>
<th>AU</th>
<th>AG</th>
<th>PB</th>
<th>ZN</th>
<th>CU</th>
<th>MO</th>
<th>NI</th>
<th>CO</th>
<th>CD</th>
<th>BI</th>
<th>AS</th>
<th>SB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Min</td>
<td>0.0050</td>
<td>0.1</td>
<td>20.0</td>
<td>10.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>0.2</td>
<td>1.0</td>
<td>5.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Max</td>
<td>0.2470</td>
<td>15.1</td>
<td>3316.0</td>
<td>845.0</td>
<td>79.0</td>
<td>13.0</td>
<td>52.0</td>
<td>41.0</td>
<td>5.9</td>
<td>68.0</td>
<td>733.0</td>
<td>67.0</td>
</tr>
<tr>
<td>Median</td>
<td>0.0050</td>
<td>0.4</td>
<td>70.0</td>
<td>72.0</td>
<td>14.0</td>
<td>1.0</td>
<td>11.0</td>
<td>6.0</td>
<td>0.2</td>
<td>1.0</td>
<td>39.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Mean</td>
<td>0.0078</td>
<td>0.9</td>
<td>120.1</td>
<td>85.9</td>
<td>16.1</td>
<td>1.8</td>
<td>11.8</td>
<td>6.9</td>
<td>0.3</td>
<td>2.4</td>
<td>43.8</td>
<td>5.5</td>
</tr>
<tr>
<td>1Stdev</td>
<td>0.0104</td>
<td>1.4</td>
<td>200.3</td>
<td>61.6</td>
<td>7.4</td>
<td>1.4</td>
<td>4.6</td>
<td>3.2</td>
<td>0.3</td>
<td>5.0</td>
<td>32.4</td>
<td>7.5</td>
</tr>
<tr>
<td>2Stdev</td>
<td>0.0208</td>
<td>2.8</td>
<td>400.6</td>
<td>123.2</td>
<td>14.8</td>
<td>2.7</td>
<td>9.1</td>
<td>6.3</td>
<td>0.7</td>
<td>10.1</td>
<td>64.8</td>
<td>15.0</td>
</tr>
</tbody>
</table>

Table 6. Table of soil geostatistical values. Min, Max, Median and Mean are all in ppm.

Significant anomalies for Ag, Pb, Bi, As and Sb exist in the soil data. For the purpose of this paper anomalies must meet at least two criteria; 1) obtain a value higher than those typically found in nature and 2) obtain a value at least equal to the upper 10\textsuperscript{th} percentile for a given element. For Ag, Pb, Bi, As and Sb the anomalous values are equal to or greater than 2.5 ppm, 249 ppm, 19 ppm, 74 ppm and 24 ppm respectively. Overall Ag displays the most robust anomalies of all the elements.

Figure 32 shows an ordinary kriging surface for Ag. The color red indicates the portions of the kriged surface that have obtained values higher than 2.5 ppm. All of the predicted anomalies cluster in one
main zone, creating one large anomaly. Table 7 displays correlation coefficients for the elements Ag, Pb, Zn, Cu, Mo, Ni, Co, Cd, Bi, As and Sb. Ag shows a minor correlation with Pb and Sb. Therefore, Pb and/or Sb may be used as pathfinder elements for Ag. Figure 33 and Figure 34 show ordinary kriged surfaces for Pb and Sb respectively. Both Pb and Sb surfaces display anomalous values where Ag also does. In terms of exploration this is would be the first area to consider.

![Image](image.png)

Figure 30. Arcmap™ image of the geology of La Recuperada. The white box roughly represents the extent of the soil grid.

However, Ag and Sb have high nugget values (55% and 68% of total sills respectively). The high nugget effect will smooth out the interpolated surface, which may hinder the prediction of anomalously high and low Ag and Sb values. On the other hand Sb has a calculated nugget roughly equal to 1% of the total sill. Therefore the Sb kriged surface will be much less smooth than the kriged surfaces
for Ag and Pb. As a result anomalously high and low areas of the kriged surface map will be more pronounced.

![Figure 31](image)

**Figure 31.** Cumulative frequency plot for Ag (30 bins). The data roughly resembles a lognormal distribution, meaning either only one population exists within the dataset or there exists multiple populations with similar distributions.

The vast majority of the rock samples collected are andesitic in origin (Figure 35). Few areas of brecciation exist on the property, although it is unclear of how it relates to the andesite porphyry. 22 quartz veins were also sampled on the property and appear to strike in a NW-SE to or E-W direction.

Unlike all other rock samples quartz veins were only assayed for Au, Ag, Pb, Zn, Cu and Bi. Similar to a lot of other polymetallic vein systems La Recuperada veins contain sporadic metal grades (potentially due to sampling bias). Metals grades reach as a high as 0.637 opt Au, 342.7 ppm Ag, 6.97% Pb, 10.8% Zn, 0.18% Cu and 1.52% Bi, while also falling to around relative detection limits. Considering the property covers almost 76 km² the likelihood for a continuously mineralized vein system is low. Where mineralized, though, moderate to high grades for Au, Ag, Pb, Zn and Bi exist.
Table 7. Correlation diagram for soil samples. Ag correlates weakly with Pb and Sb.

Numerous andesite porphyry rock samples were taken from within the soil grid. Only a few samples obtained Ag grades greater than 100 ppm, but most of the mineralized material contained grades between 10 ppm and 50 ppm. High Sb grades can also be found in conjunction with Ag (correlation coefficient = 0.411 for Ag-Sb). Sb reaches values as high as 0.2%.

Silicification and oxidation are the most prevalent alteration features found in the area, although some sericitization has occurred locally. Much of the Ag and Sb grade in the andesite porphyry is contained along oxidized and silicified fractures striking predominantly E-W to NW-SE, which is in the same direction as the quartz veins and anisotropy directions for Pb and Sb ordinary kriging surfaces (Figure 33 and Figure 34). Quartz veining was likely a late stage event that was dictated by the major preexisting fracture directions. Widespread oxidation and silicification occurred along fracture zones in the andesite porphyry and deposited low grade Ag and Sb with or without very low grade Pb and Zn.

Much of the existing rock samples did not cover the predicted anomalous Ag and Sb values from the ordinary kriging surface. The main Ag and Sb anomalies cover an area approximately equal to 0.25 km$^2$. Rock sampling also failed to extend into the northern soil grid that contained elevated Ag. While much of the sampled andesite porphyry contains low grade Ag (less than 50 ppm) the higher grade Ag may reside in largely unsampled andesite porphyry. If the majority of the highly mineralized rock has not been
sampled then it gives a false impression of the overall Ag and Sb grades in the andesite porphyry. Another possibility may be that the predicted soil anomalies are the product of the existence of several buried mineralized veins at shallow depth. More surface rock sampling of the anomalous Ag and Sb area must be conducted in order to determine the extent, grade and geology of Ag and Sb occurrence in the surrounding rock.

**Figure 32.** Arcmap™ ordinary kriging surface for Ag. Major range = 592.663, anisotropy direction = 35.4°, partial sill = 0.83549, nugget = 1.042, lag size = 50 m, number of lags = 12 and RMS standardized = 0.9657.
Figure 33. Arcmap™ ordinary kriging surface for Pb. Major range = 489.571, anisotropy direction = 339.7º, partial sill = 20468, nugget = 29158, lag size = 50 m, number of lags = 12 and RMS standardized = 0.9706.
Figure 34. Arcmap™ ordinary kriging surface for Sb. Major range = 592.663, anisotropy direction = 327.3°, partial sill = 17.501, nugget = 36.642, lag size = 50 m, number of lags = 12 and RMS standardized = 0.986.
Figure 35. Arcmap™ image of the geology of La Recuperada.

Outside of the soil grid the rock sampling density drops off significantly. Several highly mineralized veins have been identified to the south of the soil grid that contain metal grades of up to 1.27 ppm Au, 1530 ppm Ag, 10.2% Pb, 20.0% Zn, 0.13% Cu and 0.124% Bi. To the east of the soil grid several quartz veins with high metal content exist along with a few sampled andesite porphyry rocks with moderate Ag values of up to 100 ppm. It is possible that the same hydrothermal system extents to as far as 3.6 km to the east and 1.5 km to the south of the soil grid. With known mineralization in some quartz veins and andesite porphyry rocks outside of the soil grid the potential for a continuously mineralized vein system as well as continuously mineralized low grade andesite porphyry rocks exists. Considering the mineralized veins and fractures strike in the same direction more comprehensive mapping must be completed in order to accurately determine the orientations of the veins and fractures outside of the soil grid. La Recuperada is
an early stage exploration project and must be explored in more detail to determine whether high Ag grade, low tonnage ore may be extracted from a continuous vein system or whether low Ag grade, high tonnage mining may commence.

5.1.11 Cobra

Cobra is located in the eastern Cordillera approximately 12 km NW of Omoxa. The main area of interest is a 1.5 km² area composed primarily of clastic rocks such as sandstones, quartz arenites and siltstones (Figure 36) that are related to the sedimentary rocks found at Omoxa. A total of 898 rock samples have been collected in the Cobra region, but the majority of sampling focuses on a 0.8 km² section of land.

The clastic units at Cobra strike, on average, to the NW at about 315º while the clastic rocks at Omoxa strike around 290º NW. The transition of strike direction to the north from Omoxa to Cobra is gradual. Faulting does not appear to have rotated the clastic units at Cobra or Omoxa. Most of the clastic units at Cobra dip between 40º and 90º with only few samples dipping less than 30º. This could suggest that some folding exists at Cobra.

With the exception of a few samples most of the faulting is steep, dipping between 70º and 90º. A few shallow faults exist in the area and have dips as shallow as 15º. The timing of movements along the various faults in the area likely occurred roughly simultaneously and each fault may be genetically related on either a local or regional scale. The faults parallel one another (with few exceptions) and tend to dip to the SE. Much of the faulting strikes perpendicular to bedding at an average of 70º NE.

Widespread fracturing of the clastic units exists at Cobra. Similar to the faults the fractures tend to strike roughly 70º to the NE while dipping between 70º and 90º to the SE. It is possible that the fracturing of the rocks is genetically, if not spatially, related to faulting and occurred simultaneously as a result of local or regional tectonic stresses.
Alteration at Cobra is dominated by silicification and oxidation. Much of the identified oxidation on the property occurs along fractures and fault zones. The only other type of alteration identified is sericitization, which is not widespread.

Anomalous Au, Ag, Pb, Zn, Cu, Bi, As and Sb exist on the property, although no evidence of an intrusive body exist. The closest igneous rocks may reside 12 km away at Omoxa. Grades of up to 0.686 opt Au, 1063 ppm Ag, 1.0% Pb (over limit), 1.0% Zn (over limit), 1.42% Cu, 3.2% Bi, 0.38% As and 0.26% Sb have been reported. Cd and W grades, on the other hand, were mostly below detection, although a few samples reached as high as 1127 ppm and 2000 ppm respectively.
The two metals of primary interest are Au and Ag. Au and Ag are not spatially related and occur in the presence of other metals. For example Au occurs with moderate to high grade Bi while Ag occurs with moderate grade Sb. Both metal occurrences are structurally related and were deposited along oxidized fractures in the clastic units. Minor quartz veining does exist on the property and accounts for some of the Au and Ag mineralization. Similar to the widespread fracturing and faulting the quartz veins strike to the NE.

Faulting on the property contains low grade Ag, Bi and Sb, but little Au, Pb, Zn or Cu. One possible explanation for the presence of low grade Ag may have to do with a possible intrusion. As a large intrusive body ascends through the crust and reaches a relatively shallow depth the surface of the earth will react to the presence of new magma in the form of a bulge. The newly formed bulge will begin to crack at the surface. When the magma cools relatively rapidly exsolution of the vapor phase begins. As a result the volume of the magma chamber shrinks causing more fracturing of the overlying rock. These newly formed fractures would serve as vital conduits for hot metal-bearing fluids to ascend through. Metals such as Au, Ag, Pb, Zn, Cu, Bi, As and Sb were deposited along these fractures as the aqueous solutions cooled. As magmatic activity waned (as a result of the increase in dip angle of the subducting Nazca plate) in the eastern Cordillera and shifted to the west local extension prevailed. The widespread fracturing structurally prepared and controlled the direction of faulting. Ag was locally remobilized during this process and redeposited along the faults.

Cobra is a good Ag and moderate Au prospect. Fracture density is high in the area and carries moderate Ag grades. With no intrusive rock exposed at the surface it is possible that a buried intrusion is present in the subsurface. This intrusive body may contain more fracture/vein controlled Ag and Au mineralization. Further geophysical work is needed in order to determine if an intrusive body exists in the subsurface. More mapping is also recommended to further define the mineralized structures present at Cobra.
5.1.12 Cerro Iscaisca

Cerro Iscaisca is located approximately 5 km west of the town Isca Isca. Approximately 775 rock samples have been collected from Cerro Iscaisca and the surrounding mountains. The property is extensive and covers an area approximately equal to 21 km². Cerro Iscaisca has been known to geologists for quite some time as it has been mined for W, Sn, Pb, Sb and As in the past.

Cerro Iscaisca is primarily composed of porphyritic granodiorite rocks (Figure 37). To the north much of the granodiorite has been brecciated. The southern end of the property is dominated by Ordovician sandstone and siltstone with some large areas of exposed granodiorite. At or near the contact with the granodiorite the siltstones, shales and impure feldspathic sandstones have been metasomatized to tourmaline or biotite hornfels.

Alteration on the property is primarily dominated by silicification and oxidation. Only relatively small areas of sericitation and argillization have been identified. Quartz veining is abundant throughout the property. The numerous quartz veins generally trend E-W, potentially following an old geotectonic zone of weakness.

High grades for metals such as Au, Ag, Pb, Cu, Sn, W, Co, Cd, Bi, As and Sb have been found in the quartz veins. Au reaches as high as 11.7 ppm, Ag at 1395 ppm, Pb at 1.0% (over limit), Cu at 10.8%, Sn at 0.2% (over limit), W at 0.17%, Co at 0.51%, Cd at 0.16%, Bi at 0.2% (over limit), As at 1.0% (over limit) and Sb at 0.2% (over limit). The bulk of the high grades come from As followed by Bi and Au. Although much of the surface is oxidized, hypogene minerals begin to appear at just a few tens of meters depth. Most of the sulfides identified are either pyrite or arsenopyrite.

While quartz veins contain appreciable amounts of As so too do the clastic rocks and granodiorite rocks. Metal grades reach as high as 46.27 ppm Au, 72.8 ppm for Ag, 1.0% for Pb (over limit), 6.8% for Cu, 0.2% for Sn (over limit), 0.2% for W (over limit), 0.2% for Bi (over limit), 1.0% for As (over limit) and 0.16% for Sb. It is likely that the high grades found in the clastic rocks and granodiorite rocks are due to either partial dissemination or fracture controlled mineralization. No fracture information is present,
which makes it difficult to discern the truth about mineralization into the clastic rocks and granodiorite rocks.

**Figure 37.** Arcmap™ image of the geology of Cerro Iscaisca.

Future work is recommended for the continuing exploitation of W, Sn, Pb, Sb and As. Other metals that could be exploited include Au, Cu and Bi. Mapping and soil sampling is recommended to
determine the continuity of the veins and to further the understanding of the geological relationships between the veins and host rocks.

5.1.13 Chinchilhuma

Chinchilhuma is located approximately 5 km east of the town of Ciamala and 17 km east of the Chilean border. 85 rocks samples were collected over an area approximately equal to 4.4 km² adjacent to Cerro Picacho Chinchilhuaya. Much of the rock sampling was concentrated along the NE flanks of the highest peak in the area (~5,100 m).

Much of the rock within the sampling boundaries is igneous, although some sedimentary rocks can be found near river channels (Figure 38). The igneous rocks are generally composed of dacites and andesites, although some minor variations of both exist. These rocks vary in morphology and occur as tuffs, stockworks, flows or porphyrys. Tuffaceous dacites and andesites are the predominant igneous morphological feature identified at Chinchilhuma. Sedimentary rocks identified on the property include volcanic sediments. The volcaniclastic rocks are primarily confined to the northern portion of the sampling area and occur along river banks cutting through the surrounding igneous rocks.

Alteration on the property varies widely on the property. Various alteration styles identified include silicification, argillization, sericitization (phylllic included), oxidation, pyritization, and propylitic. Propylitic alteration occurs within the andesitic rocks and is generally not associated with mineralization. Silicification is abundant throughout the dacitic rocks, but far less abundant in the andesitic rocks. Sericitic alteration, however, occurs within the andesitic and dacitic rocks to an equal extent. This type of alteration is not uncommon at Chinchilhuma, meaning much of the area experienced moderate to high temperature alteration.

Quartz veining is also present at Chinchilhuma. Despite the fact that only seven samples have been identified as veins, the veining is present throughout the property. The quartz veins are polymetallic and can contain metal grades of up to 5.1 ppm Au, 275 ppm Ag, 1.3% Pb, 43.1% Zn, 2.1% Cu, 0.019%
Mo, 0.15% Cd, 0.13% As, 0.067% Sb, 2.0% Mn, and 21.2% Fe. High metals grades in the veins are sporadic however.

Figure 38. Arcmap™ image of the geology of Chinchilhuma.

The dacites, andesites and volcaniclastic rocks on the property can contain low to moderate grades of Ag, Pb, Zn, As and Mn. Therefore, the mineralizing event is likely younger than all rocks types present at Chinchilhuma. Ag is the most economically important metal found in the area in terms of abundance. Ag occurs with or without Pb, Zn, Cu, Mo, Cd, As, Sb, Mn and Fe in quartz veins. Quartz veining is fairly sporadic on the property, however, but can contain the highest metals grades found on the property. The highest Ag grades that are not associated with quartz veining are found within highly silicified rocks. Ag dissemination into the silicified igneous rocks is likely, which makes Chinchilhuma a good Ag prospect for
small to medium scale mining. A resistivity survey is recommended to identify zones of moderate to strong silicification. The presence of low grade Pb and Zn add to the value of the property and could be exploited as a by-product.

5.1.14 Avicaya

Avicaya is located approximately 3.5 km to the SE of the town of Antequera and 12 km NE of Lake Poopo. Approximately 462 rock samples have been collected from the flanks of the highest peak and surrounding drainages. Based on rock chip sample descriptions the geology of Avicaya can be separated into four distinct units (Figure 39). A granodiorite porphyry is exposed near the highest peak and is cut by dacitic subvolcanic rocks. Both igneous units intrude into a clastic unit dominated by sandstone and minor shale. To the west of the property sits an exposed upper portion of a breccia pipe.

Much of the surrounding clastic unit is fractured. The fractures likely formed in response to the intrusion of the felsic igneous rocks. Quartz veins and minor faulting have also been identified on the property. The fractures, faults and quartz veins generally trend in a W to NW direction, which is perpendicular to the regional thrust direction. Faulting and fracturing likely broke along zones of weakness, while the late stage quartz veining followed in the direction of the structurally prepared host rocks.

Alteration in the Avicaya area is characterized by widespread and pervasive silicification. All units in the area have undergone silicification to at least a moderate degree. Oxidation is also pervasive and is most intense in areas of leaching. These gossanous zones are characterized by vuggy textures, high iron content (locally reaches as high as 35.9% Fe) and moderate to strong silicification (Figure 40). Faults zones are also locally heavily oxidized and contain high iron content of up to 48.2%. Sericite is also a common alteration product identified on the property. Feldspathic sandstones, granodiorite porphyry and dacitic rocks have all undergone sericite replacement of feldspars. The last alteration feature present is argillization. Argillization affects only the igneous units and is generally weak where identified.
Avicaya rocks contain an abundance of As, covering the extent of the sampled area. As values reach as high as 11.1% and can exceed values of 1.0% in all rock types and veins. Bi is associated with As, but reaches values that are generally an order of magnitude less. As was primarily deposited along fractures, faults and within quartz veins throughout the property. Metals such as Au, Ag, Pb, Zn, Cu and
Sn are sporadically deposited along the same fractures, faults and veins, but generally fall short of reaching significant grade.

Figure 40. Arcmap™ image of the leached zones at Avicaya.

Ag, Pb, Zn, Cu and Sn are found within close proximity to the granodiorite intrusion. The adjacent clastic unit and diorite rocks can contain moderate metal grades. It is likely that the granodiorite is the source of the metals and that transportation of those metals was restricted to immediately adjacent fractures, faults and veins.

Leaching of the adjacent diorite and clastic unit began after the diorite rocks were deposited and subsequently mineralized. As descending fluids developed a much lower pH (due to the presence of abundant pyrite at the surface) some the surrounding rocks were dissolved and some mobile elements were
moved into solution. The resulting gossanous zone then retained minor Au, Ag, Pb, Sn and Cd that was not able to be leached from the descending acidic solutions.

Avicaya has moderate potential for mining on a small scale. Au, Ag, Pb, Zn Cu, Sn, Cd and Bi enrichment can be found within and adjacent to the igneous rock on the property. The property also contains widespread As with grades exceeding 10%. Cerro China Chualla (located approximately 4 km to the NE) contains the same rock units and widespread As, indicating the hydrothermal system may be extensive. Fractures, faults, leached zones and polymetallic quartz veins also exist over much of the area. The property has been structurally prepared for mineralization, although mineralization (with As aside) is generally weak. The sporadic and low to moderate Au and Ag grades in the leached zones may indicate that mineralization of mobile metals is present at depth. Overall quartz veining may hold the best potential for Ag, Pb, Zn, Cu, Cd and Sn on the property in close proximity to the igneous rocks. More mapping and sampling is required to determine the orientations of the veins as well as their grade continuity.

5.1.15 Buena Vista

Buena Vista is located approximately 50 km north of the Argentinean border and 4.5 km south of the small town called San Pablo in the western end of the eastern Cordillera. Mineralization in the area has been known for quite some time as the first workings began around 200 years ago. A total of 106 rock samples cover an area approximately equal to 5 km² that include some of the previous workings in the area. All of the exposed surface geology at Buena Vista is comprised of felsic extrusive igneous rocks (Figure 41). Ash flow tuff dominates the landscape, while smaller outcrops of dacites and rhyolites can be found in and around the area. Quartz veins have also been identified and cut through the surface units, making them younger than all the volcanics. The quartz veins follow the same strike direction as the measured fractures in the surrounding volcanic rocks. It is likely that the fracturing of the volcanic units predates the quartz veins and structurally prepared the path for veining to follow.
The most dominant alteration product exposed at the surface is sericite. Sericite alteration has been identified in all of the volcanic units and is sometimes found together with quartz and pyrite (phyllic alteration). Argillization is less abundant in the area but forms in close proximity to veins. Little evidence of alteration zoning exists although the mixed argillized and sericitized rocks immediately surrounding quartz veins quickly transitions into sericitically altered rock. However it is possible that the outer fringes of this hydrothermal system extend to greater distances beyond the boundary of Buena Vista where propylitic alteration may dominate.

The quartz veins are considered polymetallic and may contain high grade Au (up to 40.1 ppm), Ag (up to 3221 ppm), Pb (up to 39.2%), Zn (up to 26.3%) and Cu (up to 1.96). Some of the identified minerals include galena, sphalerite, chalcopyrite, stibnite, stilbite, malachite, pyrolusite and hematite. The upper
portions of the veins, close to the surface, are primarily oxidized down to a depth of only a few tens of meters. The average metal grades of the veins vary dramatically from one location to another. Some areas contain high grade metal locked up in oxide and/or sulfide material, while other areas are dominated by abundant pyrite.

While quartz veins carry the highest metal grades in the area the volcanic rocks may contain significant grades of Au, Ag, Pb, Zn, Cu, and Sb. Unlike in quartz veins where As and Sb correlate poorly with Au, Ag, Pb, Zn and Cu (Table 8), As and Sb can reach grades of up to 0.49% 0.43% respectively. Little evidence of dissemination into the surrounding volcanic rocks exists as the highest Au, Ag, Pb, Zn, Cu, As, and Sb grades in the volcanic rocks occurs within close proximity to the veins. Most of the higher metal grades in the volcanic units occur along fractures that roughly parallel the strike of the veins.

<table>
<thead>
<tr>
<th></th>
<th>AU</th>
<th>AG</th>
<th>PB</th>
<th>ZN</th>
<th>CU</th>
<th>AS</th>
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</tr>
</tbody>
</table>

Table 8. Correlation diagram for quartz veins. As and Sb correlated negatively with Au, Ag, Pb, Zn and Cu.

Buena Vista holds good potential for high grade low tonnage mining of Au, Ag, Pb and Zn. Mineralization within quartz veins potentially run as far as 3.2 km in length. The continuity and average grades within quartz veins remains largely unknown, however, given the low number of rock samples in the area. Further mapping and sampling is required in order to determine the average metal grades in the veins as well as their strike length and zone width. Considering much of the ore in the veins is sulfide the average metal grades must be sufficiently high in order to justify erecting a mill or shipping the ore to the nearest processing facility.
5.1.16 Husachata

Husachata is located approximately 16 km north of the Salar De Uyuni. It is situated in a region affected by a high degree of volcanism in the Tertiary. 35 rock samples were collected from the Husachata area that contains a multitude of quartz veins. Figure 42 shows a map of the generalized geology of the Husachata area.

Husachata geology is dominated by porphyritic rocks of diorite composition. The only other distinct igneous rock type on the property is rhyolite. However, brecciated igneous rocks can be found on the property that likely formed as a result of the porphyry intrusion. Quartz veining is also present on the property and is abundant throughout.

Alteration on the Husachata property is not dominated by one or two types, but rather contains a wide variety of types. Much of the igneous rocks have been oxidized to some degree whether it is patchy or pervasive. Silicification, on the other hand, is typically moderate to strong and occurs everywhere on the property. Chlorite is another alteration feature identified on the property and occurs distally to any significant mineralization.

Directly adjacent to some of the quartz veins is advanced argillic alteration. Surrounding other quartz veins is heavy oxidation and/or silicification. Chlorite has been identified surrounding a few quartz veins, but is generally minor occurrence. The alteration styles surrounding the veins may indicate a zoned vein deposit.

Perhaps the most important ore bearing feature in the area is quartz veining. The veins are polymetallic and can contain significant metal grades. For example, based on the limited rock sampling Au can reach as high as 5.18 ppm, 688 ppm for Ag, 17.4% for Pb, 19.5% for Zn, 11.6% for Cu, 0.16% for Cd, 4.03% for As and 0.13% for Sb. However, the grade tends to be spotty throughout the property and may contain only background metal content in distal portions of the veins.

The southeast section of Husachata contains the quartz veins with the high metal content. Here, quartz veining appears to be abundant and is found cutting the porphyry rocks, rhyolites and breccias.
Most of the veins in this area and in Husachata as a whole, strike between 60° and 90° E-NE. Prexisting structures likely account for the dominant strike direction of the veins.

**Figure 42.** Arcmap™ image of the geology of Husachata.

Although quartz veining is abundant throughout Husachata no indication of dissemination into the surrounding rocks exists. Therefore ore grade material is restricted to the veins. Husachata is a good prospect for high grade, low tonnage mining of the polymetallic veins. More sampling and mapping is required to better identify the vein orientations, vein density and metal grade continuity.
5.1.17 Berenguela

Berenguela is located approximately 150 km SW of the city of La Paz and 30 km east of Peru. The study area is extensive and covers approximately 81.6 km$^2$, although much of the focus is on a 24 km$^2$ patch. Berenguela can be broken up into three separate regions. Tatitu Kkollu resides in the SE portion of Berenguela. Anaconda resides in the extreme SE portion of Berenguela. Finally, Berenguela covers the middle and northern portions of the area. Approximately 1,434 rock samples and 16 drill holes comprise the data set. No soil data of the area exists.

Figure 43 displays a rudimentary geology map of the Berenguela area. Much of the region is dominated by Tertiary igneous rocks, although significant amounts of Tertiary sedimentary rocks persist throughout the region. Several faults and quartz veins have been identified in the area, which predominantly cut through the sandstone beds where the highest sample density exists. Faults and veins have also been identified in the massive diorite porphyry rocks, making them younger than the igneous and sedimentary rocks of the region.

The quartz veins are considered polymetallic and contain anomalously high values of Ag, Pb, Zn, Cu, Cd, Mn and As. However, the metal grades are not consistent throughout the veins. For example while grades of 0.25% Ag, 33.2% Pb, 45.1% Zn, 53.5% Cu, 3.0% Cd, 2.0% Mn and 1.86% As have been reported all metals mentioned fell below detection limit in multiple other veins. This may or may not be due to sporadic and inconsistent mineralization in the quartz veins. Another possibility is that some of the veins were selectively sampled, leading to a great disparity in metal grades.

Several different minerals have been identified within the quartz veins. Based on the alteration and mineral data both oxide and sulfide minerals exist within the veins. The minerals reported include galena, malachite, tennantite, azurite and chalcocite. Fracturing of the veins resulted in oxidation of some of the near surface minerals, while other minerals remained in sulfide form.
Evidence of a mesothermal zoned veined deposit related to porphyry style mineralization exists at Berenguela. Much of the diorite porphyry hosting the veins underwent advanced argillic alteration, while the surrounding impure sandstone beds underwent either bleaching, argillization or sericitization. Furthermore, the high grade Cu veins were predominantly formed within the andesitic porphyry, while Ag, Pb and Zn veins formed within sandstone beds. This indicates the veins within the andesitic porphyry formed at high temperatures (proximal) and that the veins within the sandstone beds formed mostly at lower temperatures (distal). Further support for the existence of vein zonation patterns can be found in Table 9. Table 9 displays the correlation coefficients between Cu, Ag, Pb, Zn, Cd, Bi and As for the sampled veins. Ag, Pb and Zn correlate positively with one another, but negatively with Cu. This can be indicative of a zoned vein deposit related to porphyry mineralization.
Table 9. Correlation coefficient diagram for quartz veins.

<table>
<thead>
<tr>
<th></th>
<th>AG</th>
<th>PB</th>
<th>ZN</th>
<th>CU</th>
<th>CD</th>
<th>BI</th>
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<tr>
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<tr>
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<td>0.514</td>
<td>0.435</td>
<td>0.487</td>
<td>-0.215</td>
<td>1.000</td>
</tr>
</tbody>
</table>

If Cu-bearing quartz veins are truly proximal to the source, then the diorite porphyry is the most likely source rock for Cu in the area. Veins as well as fractures in the porphyry carry much of the Cu grade. Some evidence of leaching exists at the surface, meaning there could be a chalcocite blanket present not far below the surface. However, good Cu grades exceeding 1.0% are not uncommon in the lahar unit and fault breccias. This potentially indicates Cu has been remobilized from within the diorite porphyry and redeposited in the lahar unit.

The lahar unit sits on top of the diorite porphyry. Lahars are fast moving, mud-filled waters associated with either a volcanic eruption or slope collapse. If some catastrophic event occurred around the Cu-bearing porphyry, then it is possible that event helped remobilize the Cu. As a result the lahar carried Cu-rich mud topographically downward and deposited it in a calmer environment. Therefore, the Cu within the lahar deposit would be considered exotic.

The last type of Cu mineralization found on the property exists in the region known as Anaconda. Here, the diorite porphyry to the north sits in contact with the sandstone to the south (Figure 44). Much of the contact between the two units is unconformable. Faulting and moderate brecciation dominate the zone adjacent to the contact. Much of the altered sandstone and porphyry on either side of the faults has undergone propylitic alteration. Farther to the south of the fault zone the sandstone and conglomerate units have undergone a combination of alteration including sericitation, argillization and silicification.
Figure 44. Arcmap™ image of the geology of Anaconda.

Much of the Cu grade is located in and adjacent to the faulted contact between the sandstone and diorite porphyry. Cu grades in the fault breccia reach as high as 11.1% and are consistently well mineralized. The surrounding sandstone and adjacent conglomerate units host good Cu grades, but less mineralized than the fault zone. Cu grades in the sandstone and conglomerate units reach as high as 2.2% and 4.5% respectively. Common to all rocks units and the fault zone is the presence of Cu oxides and low Bi, As and Sb grades. Malachite is the most abundant Cu oxide present, although appreciable quantities of chrysocolla have been reported. Unlike the rock units in Anaconda, the fault breccia contains chalcocite, which explains the relatively higher Cu grades. The preexisting fault zone (formed in response to depressurization of the magma chamber?) may have acted as a conduit for Cu-bearing fluids to ascend and later descend through. Descending Cu-bearing reducing fluids deposited chalcocite within the fault breccia.
at shallow levels. The porous sandstone and conglomerate units in the vicinity, on the other hand, acted as good hosts and allowed ascending fluids to penetrate the respective matricies and/or along fractures.

Figure 45. Arcmap™ image of the geology of central Berenguala.

Another exploration area can be found in the diorite porphyry. This unit has not been explored in much detail as only scattered rock sampling exists. The porphyry is highly fractured (formed in response to a pressure increase caused by exsolution of the volatiles from the magma chamber), which has allowed quartz veining to cut through all the way to the surface. Much of the high grade Cu, up to 36%, is not disseminated into the rock fabric, but rather is hosted either in quartz veins or veinlets.
Bordering the diorite porphyry to the west, in the heart of Berenguela, the sandstone beds may be a good host rock for Ag, Pb and Zn. The sandstone beds are cut by mineralized and non-mineralized normal faults carrying grades of up to 0.15% Ag, 10.3% Pb and 0.4% Zn. Veining and faulting in the sandstone vary in orientation, but generally strike either E-W or NW-SE. The faults likely provided a good pathway for fluids to move through and disperse into the highly fractured sandstone. Quartz veins followed the paths of the preexisting structures, which explain their similar orientations. The mineralization within sandstone beds may represent the upper extent of the porphyry system.

Figure 45 shows the distribution of Ag throughout a portion of Berenguela. High grade Ag can be found in close proximity to the quartz veins and normal faults. Grades of up to 599 ppm Ag can also be found up to 300 m away from any observed structure, indicating either dissemination into the sandstone
occurred or that Ag was deposited along abundant fracture zones that exist in Berenguela. With high grade Ag existing in portions of the quartz veins, faults and sandstones the possibility for large tonnage open pit extraction exists.

Tatitu Kkollu is the last area of interest within Berenguela. The geology of the area is composed of rhyolites, tuffs and volcaniclastic sediments (Figure 46). Alteration in the area includes a wide range of alteration types such as silicification, argillation, sericitation and oxidation.

Surface sampling indicates moderate grades exist for Ag, Pb and Zn with sparse Au. Most of the Ag, Pb, Zn and Au grades are hosted in the volcaniclastic unit. The silicified volcaniclastic rocks host much of the Ag grade with or without low grade Zn. However in the argillized volcaniclastic rocks, Zn is moderate grade (occasionally high grade) and is generally not associated with Ag mineralization. The contact between silicified and an argillized volcaniclastic rocks is a hard boundary. While the better Zn grades in the silicified rocks are found close to the silicified-argillized contact and the better Ag grades are found in the argillized rocks close to the silicified-argillized contact a hard boundary exists between the two. This is due to the fact that Zn and Ag mineralization away from the contact diminishes rapidly within silicified and argillized volcaniclastic rocks respectively. A resistively survey is needed to better determine the subsurface alteration at Tatitu Kkollu. This would aid in target delineation for the separate Ag and Zn targets.

A total of 19 holes have been drilled in Berenguela, but only 8 contained collar coordinates and downhole information. 12 holes were drilled into the sandstone unit in the heart of Berenguela, 4 were drilled south into Tatitu Kkollu and 3 were drilled in Anaconda. However no hole came with log data. The subsurface lithology and structure remains a mystery.

Despite the lack of concrete drill data surface rock sampling was extensive in certain areas. Anaconda is a candidate for a structurally controlled porphyry related Cu deposit. High grade Cu-bearing chalcocite within the fault breccia, moderate to high grade Cu oxides and high fracture density within the adjacent porphyry, sandstone and conglomerate units indicate Cu has been remobilized and redeposited in the area. With the diorite porphyry exposed at the surface north of the fault zone it is likely that the
porphyry contains moderate hypogene Cu grades at depth. Anaconda holds high potential for high tonnage, low-moderate grade Cu.

The heart of Berenguela also has the potential to be mined. The primary sandstone host rock is cut by E-W to NW-SE trending normal faults. Some of the faults are mineralized and contain significant grades for Ag, Pb and Zn. The sandstone is highly fractured, providing mineralizing fluids with an adequate pathway in which to follow. Polymetallic veins contain some of the highest grades on the property. The combination of highly mineralized faults, fractured and veins makes the heart of Berenguela a good Ag, Pb and Zn prospect for open pit mining.

Tatitu Kkollu is perhaps the most important area for Zn exploration. Although other metals such as Au, Ag and Pb are present in moderation at the surface, Zn is the most widespread and continuous metal found at Tatitu Kkollu. The volcaniclastic host rock is dominated by argillization to the south and silicification and argillization to the north. Zn grades are moderate in the argillized volcaniclastic rocks, while Ag grades are moderate in the less pervasive silicified rocks. The continuity of the Zn grades at the surface indicates there could be reasonable low to moderate grade Zn at depth. A resistively survey would be needed to distinguish between the argillized and silicified zones.

5.2 Landsat™ Data

Six Landsat™ images were taken primarily over the southern portion of Bolivia. Processing of Landsat™ images can yield vital information into the rocks that cover the photographed surface. The six Landsat™ images were taken over regions where little to moderate information about rock type and the presence of ore bodies is known. The first step in analyzing surficial geology of Landsat™ images is to produce ratio images.

Ratio images are created by combining various reflectance band into a red-green-blue composite. Each of the six Landsat™ images within the dataset contains bands 1 (0.45-0.52 µm), 2 (0.52-0.60 µm), 3 (0.63-0.69 µm), 4 (0.76-0.90 µm), 5 (1.55-1.75 µm) and 7 (2.08-2.35 µm). In theory, by dividing band 7
by band 5 clay minerals, if present in large enough quantities on the surface, will yield a high reflectance value (bright) due to the fact that clay reflects more energy in the wavelengths covered by band 5 than by band 7. If little or no clay material exists then the reflected energy emanating from clay will be low and, as a result, the feature will appear dark.

When different ratios are created they can be combined into a single red, green and blue composite. For example assigning 5/7 to the green band, 5/4 to the red band and 3/1 to the blue band will create and clay, ferrous and iron oxide composite image. By studying the range of colors produced (variations of responses will produces various in between colors) it is possible to determine the likelihood of clay, ferrous and iron oxide minerals existing in particular areas on the photographed surface.

From the ratio images the goal is to determine areas of alteration. Because alteration is generally associated with ore bodies locating surficial alteration zones can provide a starting point with which to further explore. Also, by analyzing vegetation patterns (through ratioing) it is possible to determine soil type. Regions rich in arsenic, for example, may kill plant life and leave a surficial signature. However, soil prediction from the limited indicies provided by Erdas Imagine™ 8.7 is not feasible. Instead a detailed vegetation analysis of each image has been conducted.

5.2.1 Image 227_73_I7

5.2.1.1 Vegetation

Image 227_73_I7 is located over the Bolivian city of Puerto Suárez (center-bottom) with the far right section residing over eastern Brazil. Due to the known lack of topography and exposed rock two composite ratio maps were created that included NDVI, Vegetation Index, Clay Minerals and NDVI, Vegetation Index and IR/R. Based on the rudimentary vegetation map (Figure 47) this image is dominated by marsh, open scrub woodland, grassland savanna, palm and riverine forest. Results from the ratio maps agree quite well with the present documentation.
The Paraguay River flows from north to south in an anastamosing fashion. Areas adjacent to this river and smaller river systems in the vegetation composite image (IR/R [red], NDVI [green], Vegetation Index [blue]) show up as bright white (Figure 47). White indicates that equal proportions of the red, green and blue exist and are equal to the end member value. This means that these areas have high green (healthy) vegetation density; i.e. riverine forest.

**Figure 47.** Landsat$^\text{TM}$ band stack ratio image of image 227-73-17. IR/R = red band, NDVI = green band and Vegetation Index = blue band.

The lakes in the vegetation composite image show interesting results. The two largest lakes in the image (Lagoa Mandiore and Baia Conceicao located in the upper portion of the image) show up as
predominantly black, but with scattered patches of pale red color. Most of the other lakes appear predominantly pale red. When isolating the blue layer all the lakes appear black, meaning the red color found within most of the lakes originates solely from the red layer or the IR/R layer. The patches of red indicate areas where there are equal reflectance values of greater than 0 and less than 1 for bands 3 and 4. This indicates that at the time this Landsat™ image was produced the sections of the lakes with red represent the dried up regions where mostly dead plant material or barren ground exists. The spotty reds within the other lakes probably represent either dry patches of barren ground/mostly dead plant material or, less likely, algae mats.

The rest of the image shows various combinations of blue and red to form deep purples and dark pinks. Smaller river systems tend to have brighter purple combinations indicating these areas contain denser vegetation. The lack of green in the images indicates most of these other river systems contain either a greater percentage of unhealthy vegetation or non-green leaf vegetation such as a grassland or savanna. Greater distances away from river systems tend to appear dark purple where vegetation health is likely poor due to a lack of adequate water. This image was likely taken during the dry season (July, August, and September).

5.2.1.2 Surface Geology

Clay content was also analyzed in an iron oxide (red), ferrous (green) and clay mineral (blue) stacked ratio map (Figure 48). Approximately 80% of the image appears grey indicating equal proportions of red, blue and green. When the clay ratio band was isolated approximately 90% of the surface appeared a dull blue indicating the reflectance ratio of 5/7 approached one. Either clay material is present, but highly obscured by vegetation or the resulting color combinations, when all bands are active, indicate a highly heterogeneous environment with combinations of many different materials.

Lagoa Mandiore and Laguna Puquio appear purple in the mineral composite, lacking any color contribution from the green band. This may indicated a highly oxidized environment where silts and clays
exist as suspended sediment in the case for only Lagoa Mandiore. Silts and clays may exist within the boundaries of the primarily dry Laguna Puquio. Other purple and turquoise regions appear in areas adjacent to the Paraguay River, primarily in the flood plains. Here clays and iron minerals may have been deposited in the past during flooding. The southeastern section of the image contains patches of bright green south of the city of Corumba (appears dark purple in the vegetation composite). This area potentially has been cleared for use by humans, exposing much of the underlying lithology and basement rocks.

Figure 48. Landsat™ band stack ratio image of image 227-73-17. Iron oxide = red band, ferrous minerals = green band and clay minerals = blue band.
5.2.2 Image 228row73

5.2.2.1 Vegetation

Image 228row73 contains a few interesting features when compared to 227_73_17. Considering about 15% of the two images overlap one might expect the vegetation trends to remain approximately the same. However, this is not the case.

The ratio stacked image (IR/R, Vegetation Index and NDVI in red, green and blue respectively) produces a dominantly bright pastel blue image (Figure 49). When the blue band is isolated much of the image appears medium blue. The medium color indicates moderately dense green vegetation spread throughout the image. The high percentage of green land also indicates this image was taken during the wetter season (December, January or February). This medium blue color is not as intense as the bright green color surrounding the Paraguay River due to the annual fluctuations in rainfall compared to the consistency of adequate drainage rates of the Paraguay River.

Viewing only the green and red bands together the image appears in various forms of yellows. Virtually all black in the image is nonexistent indicating few lakes exist and the ones present lack significant size. Darker yellow regions are found in areas of moderate topography. These areas probably contain less vegetation due to high runoff and erosion rates, giving plant material less time to grow and survive during the rainy season. As expected areas of low relief display brighter shades of yellow indicating greater vegetation density in comparison to the moderate topographic regions. Here lower erosion rates, lower runoff rates and high rainfall induces plant growth. Much of the lower relief areas are probably composed of lush grasses and dispersed woodlands.
5.2.2.2 Surface Geology

A mineral composite ratio map was created (ferrous minerals, iron oxide and clay in red, green and blue respectively) to find weathered material, altered material and exposed rock (Figure 50). Unlike the previous image where 80% of the land area appeared gray 85% of this composite appears purple, indicating a lack of green and, hence, iron oxide minerals. Much of the purple areas probably reflect
surfaces containing various amounts of clays and, most likely, high concentrations of weathered iron minerals dispersed throughout plant material.

The higher topographic regions, where runoff is highest (especially during the wet season) adjacent patches of bright greens, yellows and reds appear. The reds probably indicate areas of highest runoff where rocks are, consequently, exposed. These rocks may be granitoids or schists that form the upper section of the basement rocks.

*Figure 50.* Landsat™ band stack ratio image of image 228row73. Ferrous minerals = red band, iron oxide = green band and clay minerals = blue band.
The greens may represent areas of high oxidation, such as small lakes and low energy rivers. The yellows occur within close proximity of the greens and red indicating the iron may have eroded off of the exposed rocks in the highlands and been deposited in the lower energy fluvial environment where oxidation may have taken place.

5.2.3 Image 229_74

5.2.3.1 Vegetation

Similar to image 227_73_l7 image 229_74 (located in northern Paraguay, just southwest of image 228row73) was taken during the dry season. A composite image of IR/R, NDVI and Vegetation Index in the red, green and blue bands respectively was created (Figure 51). When isolated the green band appeared approximately 99% black indicating there is virtually no difference in reflectance between bands 3 and 4. The few bright green areas are located adjacent to small rivers where minute pockets of year-round green vegetation exist (probably riverine forest).

After isolating the red and blue bands the image primarily appeared in dark shades of red. Here reflectance from band 4 was less than that from band 3 giving a 4/3 ratio of less than one. Considering healthy green vegetation reflects more than 6 times as much near infrared energy as unhealthy vegetation primarily unhealthy vegetation exists in this image mostly due to the effect of the dry season. This effect is strongest in the southwest corner where the dominant color approaches black. Much of the image surface is composed of unhealthy vegetation in the form of dry grass and woodland.

A mineral composite was created (clay, ferrous minerals and iron oxide in red, green and blue respectively) to look for clay minerals and any exposed iron-bearing rocks (Figure 52). The resulting composite produces various browns, greens and blues. Interestingly the southwestern section of the image produced inversely proportional spectral intensities for ferrous and clay minerals. This section results from
the combination of bright greens and dark reds. Consequently this region may contain sections of exposed rock, potentially basement material of granitic composition.

Figure 51. Landsat™ band stack ratio image of image 229_74. IR/R = red band, NDVI = green band and Vegetation Index = blue band.

5.2.3.2 Surface Geology

Scattered slightly dark light green areas correlate with medium blues to form pastel blues in the mineral composite image (the few scattered blues only occur in regions of dark reds, where little to no clay material exists). These areas may represent highly oxidized environment near low energy fluvial
environments. In the upper right section of the image a road leads up to a pastel blue feature. This feature contains some water within its boundaries represented by blacks and very dark blues. A lack of red in the surrounding sea of pastel blue may indicate areas of highly eroded iron-bearing material, feeding the fluvial environment large quantities of iron and forming clays at greater distances away.

**Figure 52.** Landsat™ band stack ratio image of image 229_74. Clay minerals = red band, ferrous minerals = green band and iron oxide = blue band.

### 5.2.4 Image 231_74

#### 5.2.4.1 Vegetation

Image 231_74 is located in southern Bolivia over the Eastern Cordillera, Interandean zone and Subandean zone near Tarija. Due to the greater altitude of the Eastern Cordillera to the west compared to
Interandean zone to the east in this image vegetation changes drastically across this region. The Interandean zone consists of north-south trending peaks and valley approximately residing perpendicular to the major wind direction. Storm systems originate to the east and carry moisture westward across this zone. These ridges and valleys are higher in altitude and cooler in temperature compared to the adjacent plain to the east so the increased rainfall in this area promotes greater forest vegetation growth. Evidence for this relies on the green output in the IR/R (red), NDVI (green) and Vegetation Index (blue) ratio band stack image (Figure 53).

The eastern slopes of the Interandean zone receive more rainfall per year than the western slopes and valleys. As a result bright green areas appear in great abundance on the eastern slopes. A local rain shadow effect is caused by the ridges and forces moisture fall as air rises above the eastern slopes, permitting forest growth. Because the bright green areas only appear on the eastern slopes it must indicate the Landsat™ image was produced during the dry season (further explanation later in this section). The bright green areas probably represent high altitude trees that remain green year round.

The far right section of the image represents the border between the Subandean zone and the plains of Bolivia. Here the red and blue bands, when isolated, produce dark purple to black colors. During the wet season this area should appear bright purple indicating healthy vegetation as is the case for image 228row73. Since this is not the case the likely scenario points to the conclusion that this image was produced during the dry season. Further evidence supporting this conclusion can be found by analyzing the subdued purples located within the valleys and on the western slopes of the Interandean and Subandean zones. At higher altitudes mountain forest trees will thrive whereas other trees will die. The warmer valleys should primarily contain grasses with scattered lower altitude/warmer climate trees. It is possible that more trees exist in this region but are not considered healthy due to a lack of chlorophyll to reflect near infrared energy. On the western slopes, however, the high altitude in conjunction with lower rainfall totals probably prohibits the growth of dense patches of trees. Primarily grasses and shrubs with scarce conifer trees dominant this region.

In the Eastern Cordillera section (western half) of this image very little vegetation is present. The combination of high altitude and a regional rain shadow effect essentially prevent most forms of vegetation
from thriving. Subdued reddish colors indicate the low reflectance values for band 4. With little vegetation reflecting near infrared energy back into space the blue band produces blacks and the red band produces pixel values less than one. Only areas of high relief receive enough rainfall to support some plant growth, probably in the form of grasses, shrubs and scattered conifers.

Figure 53. Landsat™ band stack ratio image of image 231_74. IR/R = red band, NDVI = green band and Vegetation Index = blue band.

5.2.4.2 Surface Geology

A band stack ratio image was created using the following ratio 5/4 (ferrous minerals, red band), 5/7 (clay minerals, green band) and 3/1 (iron oxide minerals, blue band) (Figure 54). When isolated the green band displays light greens with minor amounts of bright greens across the Interandean and
Subandean zones. This region forms the frontal section of the active fold and thrust belt. According to some geologists (Kley, 1996; Schmitz and Kley, 1997; McQuarrie, 2002) this region is dominated by Silurian-Devonian marine clastic rocks. When all three bands are viewed at the same time this region remains light green indicating the lack of ferrous and iron oxide minerals. Hence the only spectral response is in favor of the presence of clay minerals.

Unlike quartz clays and shales tend to have absorption features between 2.1 and 2.3 μm wavelengths (due to ionic vibrations) which could account for the light green spectral response and indicate a broad alternating zone of various shales and marine sandstones. This seems geologically feasible considering marine clastic rocks tend to form deposits that do not exceed hundreds of meters due to sea transgressions and regressions. One Landsat™ pixel roughly accounts for a 30 by 30 meter area. The majority of pixel colors in this region would then result from the combination of clay, shale and sandstone reflectance.

Scattered small bright green areas exist in the Interandean and Subandean zones which may indicate areas where the clay and/or shale outcrops exceed a 30 by 30 meter zone. The far right section of the composite produces browns and pinks. The brown results from a larger percentage of the red band contributing spectral reflectance to the image. Here, a local basin resides at a low enough elevation between various ridges. Vegetation is sparse which may leave exposed igneous rocks units visible. The small presence of green may be determined by local drainage patterns bringing a high percentage of sedimentary rock source material in.

Isolating the red and blue bands produces blues, pinks, dark reds and reds. For the interest of this paper only the pinks provide any significant information. The rest of the colors result from either equal combinations of both bands or one band such that the spectral response approaches one, meaning no variations in spectral reflectance between given bands and, hence, can tell us little about the surface material. The pinks may be the result of local outcroppings of igneous material within the highly folded sedimentary units. An unknown river cutting through the southeast section of the image appears mostly gray, but medium blue when isolated. It probably carries varying amounts of sedimentary and igneous material shed off of the Eastern Cordillera.
Electronic transitions, generally caused by the presence of iron, create absorption features in band 4, but not in band 5. Regions of high iron content should produce a high spectral reflectance in the red for this case. Bright red regions, once the red band is isolated, trend north-south in the image and are concentrated in the middle-left section. Here, vegetation is sparse allowing greater spectral responses from rock units. This region appears pink in the mineral composite, implying a stronger red contribution than green and blue. The strong presence of red may indicate exposures of igneous material. The Eastern Cordillera is a considered the back arc section of the subduction complex, meaning mafic material may
exist in scattered locations. Considering the lack of back arc volcanism and high reflectance values the
pinks probably represent areas of high relief containing exposed granitic material.

Much of the eastern third of the image appears as a pinkish gray. Here reflectance values for each
band are roughly equal. The Eastern Cordillera is known for being in a highly erosive environment. With
all types of rocks experiencing high rates of erosion, a highly heterogeneous environment probably results.
As a result the lithology of this region cannot be accurately constrained.

Sections of aqua colors appear in the western end of the image. Here the red component
contributes the least amount of reflectance energy. The aqua areas seem to be concentrated in where
tributaries exist. Perhaps the source regions lack significant iron-bearing minerals. There also exists a
small lake in the southeastern portion of the image. The area is covered by green and aqua colors, possible
implying a high concentration of clay units within and surrounding the lake.

In the original image there appears to be a dark feature directly north of the lake by approximately
50 km. When viewed in the mineral composite pinks, oranges, greens and aqua colors comprise the area.
It is difficult to tell what this feature is. The only conclusion to reach is that it is of heterogeneous material
that potentially contains varying amounts of perhaps magnetite and other minerals.

5.2.4.3 Structure

5 by 5 high pass horizontal and vertical filters were used in an attempt to locate structural trends in
this image (Figure 55 and Figure 56, respectively). In the right half of Figure 56, where the Interandean
and Subandean zones reside, bold north-south trending lineaments appear that span the length of the image.
As mentioned earlier this area is the frontal section of the active fold and thrust belt. Volcanism has not
disrupted this area, effectively preserving the structural trends. Considering convergence between the
Nazca and South American plates is roughly east-west it comes as no surprise that the dominant structural
trends are located in the north-south direction. The 5 by 5 horizontal filter supports this notion because
practically no structural trends appear in this image.
The western half of the image, located within the Eastern Cordillera, displays far less structural trends. This section contains Cenozoic volcanic material that may hide some of the structural features. North-south trends can be seen but are not as clearly defined as the eastern half of the image. Small horizontal trends show up with more clarity than they do in the eastern half of the image. These structural features tend to max out at approximately 500 meters in length and probably result from local and/or regional stresses within the crust.

**Figure 55.** East-central snapshot of 5 by 5 horizontally filtered image derived from image 231-74. East-west trends exist in small numbers and tend to traverse over minimal distances.
Figure 56. East-central snapshot of 5 by 5 vertically filtered image derived from image 231-74 (same coverage as in Figure 55). North-south trends exist in large numbers and tend to traverse over large distances.

5.2.5 Image 232row71

5.2.5.1 Vegetation

Image 232row71 was taken in a location slightly northwest of the city Puerto Patino in the Chaco Plain. A vegetation composite was created (IR/R in red, NDVI in green and Vegetation Index in blue) that created various colors including black, bright green, deep purples and burgundy (Figure 57). When isolated the green band appears lime green over greater than two-thirds of the image. A large river called the Mamore River flows through the right-center portion of the image where much of the lime green color appears. The bottom half of the image also contributes a significant amount of green to the image where tributaries combine to form the Mamore River. Lime green represents areas of green vegetation.
Figure 57. Landsat™ band stack ratio image of image 232-71. IR/R = red band, NDVI = green band and Vegetation Index = blue band.

When all the vegetation bands are analyzed in a single image the lime green areas appear brighter green to nearly white in some locations. This indicates that the green vegetation is healthy and very dense in some locations. Much of this dense plant material resides near the many tributaries within the image.
The burgundy and purples result from the combination of blue and red with little to no green input. These areas do not contain green vegetation, but are probably composed of grasses, palm trees and/or woodland with moderate density. The black regions represent lucastrine environments.

5.2.5.2 Surface Geology

A composite image (clay in red, iron oxide in green and NDVI in blue) was created primarily to analyze the clay and iron oxide content of the image (Figure 58). When the red and green bands were analyzed together the resulting image produced little color combinations, bright green and various red intensities, implying an inverse relationship between the red and green bands. The Mamore River and its many tributaries appeared bright green, indicating high iron oxide content. The relatively close proximity to the Andes Mountains coupled with warm wet conditions produces a highly oxidized environment within fluvial regions. Curiously cloud cover in the southern section of the image produced the same result. The iron oxide ratio is 3/1 which covers the reflectance of water. However, the reflectance for water does not exceed about 15% (and varies only slightly) anywhere in the visible range so it is slightly baffling to see such a high reflectance response from cloud cover.

The red band nearly appears black in regions where water exists. Perhaps no clay exists in these areas or the water levels are too deep to penetrate. Regions seemingly away from water sources, but within floodplains, appear the brightest in the red band. Warm wet environments with high vegetation densities produced large amounts of clay as seems to be the case in this image.
5.2.6 Image tm232_74_051186

5.2.6.1 Vegetation

Considering the location of image tm232_74_051186 one would expect vegetation reflectance values to be low or non existent. The NDVI band of the vegetation composite (IR/R, NDVI and Vegetation Index in red, green and blue respectively) appear throughout less than 1% of the image area (Figure 59). At altitudes greater than 5,000 m and little rainfall deciduous tree cannot survive. Low valleys between peaks probably contain scattered deciduous trees in low quantities.
Figure 59. Landsat™ M band stack ratio image of image 232-71. IR/R = red band, NDVI = green band and Vegetation Index = blue band.

Much of the image is dominated by red with scattered areas of blacks (lakes) and purples. The purples tend to following drainage patterns and appear to have moderate vegetation density. Minor amounts of purple and pinks surround lakes in the image, indicating moderately dense healthy vegetation. The remaining areas of the image appear as a pale red. A relatively low reflectance in red combined with little or no contributions from the green or blue bands indicates the land does not contain high density biomass. As a result more than 99% of the image is dominated by high altitude bunch grass and scattered scrub.
5.2.6.2 Surface Geology

Up to 80% of the mineral composite image (clay in red, ferrous minerals in green and iron oxide in blue) appears a dull gray (Figure 60). As mentioned earlier the Eastern Cordillera is located in a highly erosive environment, in which this image was taken. The gray results from having practically no reflectance values or relatively equal proportions of reflectance values from the red, green and blue bands. In terms of assessing areas of mineral potential the gray areas give no indications of potential mineral prospects.

The purples in the mineral composite result from the combination of medium red, medium blue and dark green. Purples follow drainage patterns where vegetation is moderately dense. Here high altitude dry soils persist which could account for the low red reflectance.

The green areas represent possible regions where mineral potential exists. Lime green results from having a larger reflectance from the green band. Previous mapping of the Potosi region (upper middle portion of the image) defines the geology of this area as a mixture of undifferentiated intrusives, rhyodacite lavas and tuffs, quaternary sediment cover, continental sediments (conglomerates, sandstones, pelites), limestones and calcareous sandstones (Figure 61). The lime green areas likely represent volcanic material ranging in composition anywhere from granite to andesite. The aqua colors result from having minor amounts of blue and red contributing to high amounts of green. These regions may contain a mixture of felsic igneous and continental sedimentary rocks.

Burgundy colored areas offer yet other places to begin searching for mineral deposits. The burgundy colors located in the middle and southeastern portions of the image represent oxidized stream channel rocks and sediment that are likely unrelated to mineral deposits. However, other burgundy areas that do not appear to have a stream or river morphology are good candidates. These areas contain a high degree of iron oxides minerals that could be related to high sulfidation hydrothermal systems.

Very little pink exists but results from a mixture of dark green, medium blue and medium red. Again this is another heterogeneous environment that probably contains a mixture of felsic igneous rocks
and continental sedimentary rocks. Areas comprising lakes appear as adjacent blocks of orange, green, blue, aqua, red, yellow and orange. These lakes probably contain varying amounts sedimentary clastic, marine calcareous and igneous derived sediments, considering much of the material draining into these lakes probably comes from areas of gray reflectance. Finally the brown regions probably represent areas of clays, shales and/or sandstones due to the combination of medium red and dark green.

**Figure 60.** Landsat™ band stack ratio image of image 232-74. Clay minerals = red band, ferrous minerals = green band and iron oxide = blue band.
5.2.6.3 Structure

Considering the location of image tm232_74_051186 it makes sense to predict the dominant structural trends aligning north-south. High pass 5 by 5 vertical and horizontal filters were created to analyze the structural trends within the image (Figure 62 and Figure 63, respectively). As expected the dominant structural trends aligns roughly north-south. Perhaps due to magmatic process below the crust
and volcanic activity on the surface these structural trends are not as long (only on the order of a few hundred kilometers) or as defined.

Figure 62. North Potosi snapshot of 5 by 5 vertically filtered image derived from image 232-74. North-south trends exist within the confines of the large igneous feature.

East-west trends do exist but not as defined or as long as the north-south lineaments. They tend to max out at approximately 50 meters and are most clearly seen in the Potosi region where a large igneous dome resides in the northeast section of the image. Around the massive dome most structures align north-
south but within and along the perimeter they align more east-west, probably the result from local stresses within the crust due to magma injection.

Figure 63. North Potosi snapshot of 5 by 5 horizontally filtered image derived from image 232-74 (same coverage as in Figure 62). East-west trends exist along the perimeter and within the western half of the large igneous feature.

5.3 Geophysical Data

Geophysical data provides vital information about either the size of a sulfide body or about the radiometric counts and magnetic response of a particular region. Airborne magnetic data can detect highly
magnetic intrusive bodies at depth that soil or outcrop geochemical sampling may not detect. Magnetite is the primary magnetic mineral that airborne magnetic surveys pick up and tend to be associated with basic rocks (if magnetic response is at depth). However the range of magnetic responses for all lithologies can vary significantly. In order to tell if an anomaly with economic potential exists geochemical sampling must occur. A magnetic anomaly alone cannot definitively determine rock type or geochemical provinces.

Airborne radiometric surveys test for U, K and Th. Radiometric surveys can determine if anomalous populations of U, K, and/or Th exists on the surface. This is important because rocks containing elevated rare earth elements (REE) and large ion lithophile elements (LIL) can be associated with Au, Cu and phosphate deposits among other things. Radiometrics provide a first order approach into finding ore bodies and cover large land area.

Ground based geophysical survey is generally done as part of a follow-up survey. Induced polarization (IP) surveys can detect the presence of sulfide bodies at depth and help to determine the extent of sulfidation. Once geochemical sampling (soil, outcrop, drilling etc.) has detected the presence of sulfide related mineralization IP surveys can determine, roughly, to what degree sulfidation exists in the region. Higher values of 70 mrad and up are generally regarded as worthy of consideration. As a general rule of thumb 5 mrad ≈ 1% sulfide. After and IP survey has been conducted and analyzed resource estimates can be made based on the extent of sulfidation.

5.3.1 Eastern Cordillera, Subandean Zone, Interandean Zone and Potosi

Geophysical data acquired from northern Potosi includes measurements for total magnetic intensity (TMI), first vertical derivative TMI, second vertical derivative TMI, inverse resistivity, inverse chargeability, potassium %, thorium %, uranium % and potassium/uranium % (Figure 64). Study area #1 resides to the southeast of Lago Poopo and in the northern section of image 232-74.
A secluded strong magnetic dipole exists in region where covering Colavi. This area contains rock samples with dispersed elevated Ag, Pb, Zn, Cu and Sb values derived primarily from outcrop. The strong dipole (ranging from approximately -204 nT to 619 nT) exists directly beneath samples containing elevated Cu and Ag values. Unfortunately the study area does not cover the negative end of the anomaly, so it is unclear whether further enrichment of these chemical species exists in this area. Based on the size...
of the anomaly depth to the magnetic body approximately equals 6 km (general equation = \( \frac{1}{2} \) width of anomaly). It is possible an intrusive igneous body at depth fed mineralized fluid to emanating veins reaching the surface.

Another secluded, but less intense, dipole exists in the southern section of the study area. The positive end reaches approximately 87 nT and the negative end reaches about -35 nT. The anomaly covers a distance of almost 13 km and resides adjacent to another broad positive anomaly reaching 250 nT. It is unclear as to whether the positive anomalies both contribute to the slight negative region or if they are partial products of edge properties. It is possible that the magnetic response is fault controlled due to the presence of major Cenozoic thrusting. Nevertheless the anomaly probably represents a highly evolved igneous body at depths approaching 7 km.

The rest of the study area contains irregular anomalously high and low magnetic responses. Towards the center and to the northwest the positive anomalies reach values of up to 317 nT while the negative anomalies reach values as low as -228 nT. The irregular and seemingly random high and low magnetic responses probably indicate a region that experienced massive faulting and plutonism. Each anomaly probably results from the combination of more than one igneous body. Considering the study area resides in the eastern Cordillera it is possible that mafic igneous bodies exist at depth contributing to some of intense magnetic responses.

U, Th and K grids were created for study area #1 and revealed areas of potential alteration. As expected U and Th values approached percentages of 8.5 and 46, respectively, for the enormous dome located west of the city of Potosi. The dome complex boundaries are clearly defined by the elevated U and Th values adjacent to low U and Th values. The adjacent low U and Th percentage regions are comprised of marine clastic rocks and limestones (results from the immobility of U and Th). Other regions elevated U and Th percentage exist to the west of the city of Potosi and are scattered within the northern section of the study area. Elevated U and Th regions probably represent areas of highly evolved igneous material exposed at the surface.

Elevated K regions roughly coincide with elevated U and Th regions. The large dome complex west of Potosi contains overall moderate K values with isolated elevated areas reaching as high as 7.4%.
Surprisingly, Tollocci only produced moderate K percentages to go along with elevated U and Th percentages, potentially indicating only moderate alteration in the region. The western third of the study area produced the highest K percentages and appeared to cover a broad area. K percentages reach as high as 7.7. Ratio maps contradict the K grid by suggesting this region contains elevated iron and iron oxide content with minimal clay minerals present. Perhaps K is obscured from satellite images by overburden or is present in ancient lake minerals such as sylvite, carnallite, langbeinite and polyhalite that do not contain the same spectral properties as clay minerals.

Study area #2, located over the Colavi region, contains extremely low U and Th values that approach 0. However, high U and Th values cluster within a small region that coincides with the zero point of the strong dipole anomaly. U and Th values reach as high as 4.9% and 27% respectively. These anomalies probably represent local exposures of igneous veins that produced elevated Ag and Cu anomalies.

The northernmost section of the study area resides probably less than 10 km east of Lago Poopo. Broad positively and negatively coupled anomalies cover much of the southern half of the study area. Subparallel regions of alternating positive and negative magnetic responses dominate this region. It is likely that the series of subparallel alternating anomalies are structurally controlled by predominantly north-south trending faults. However, no satellite imagery of this area exists, making the previous statement a broad generalization. Positive anomalies reach as high as 118 nT and negative anomalies reach as low as -98 nT.

The northern half of the study area contains northwest-southeast trending subparallel positive and negative anomalies. Some of the anomalies stretch to distances of approximately 23 km in (strike) length. This area also appears to exhibit structurally controlled magnetic responses. The linear magnetic anomalies could arise from a highly dissected igneous body at depth.

U within the eastern half of the study area produced elevated percentages as high as 15 and Th percentages as high as 25. K reach values as high as 8.8% and roughly correlated with regions of elevated U and Th. In general the northeastern section of the study area contains the highest U, Th and K percents. Perhaps the region contains exposed felsic material consisting of moderate scattered alteration.
5.3.2 Tollocci IP

Geophysical data present in the Tollocci region contains magnetic, inverse chargeability (1/M) and inverse resistivity (1/ρ) information. However, all magnetic data were derived from GXF files and do not contain coordinates. As a result only two-thirds of the local geophysical data is usable and is confined to the southern half of Tollocci.

Resistivity and chargeability surveying was designed to penetrate down to depths of approximately 230 meters. Nine depth levels were recorded for each station in which 1/M and 1/ρ values were given. Inverse resistivity yielded values ranging from 3.287 V/mV to 48860 V/mV which translates to a range of approximately 0.000 mV/V to 0.304 mV/V. Inverse IP ranged from 0.0 1/ms to 82.0 1/mrad, which translate to IP values ranging from 0.0 ms to 0.01 mrad. It seems likely that the inverse resistivity and inverse IP values should be considered resistivity and IP values instead.

Large sulfide deposits have been documented at Tollocci. If the documentation is correct then IP values should, on average, be at least equal to 5 mrad (and IP value of 5 mrad roughly corresponds to 1% sulfides). IP results indicate large sulfide deposits exist at up to 16%, which is quite a large percentage. Coupled with elevated Ag and locally elevated Zn values makes the southern end of Tollocci (Juchuy Tollocci) a prime location for economic Ag and Zn potential.

Grids from study area #3 are split up in sections and can only be viewed one at a time instead of collectively. Therefore presenting the results by grid is the most effective way to communicate the findings. Positive and negative magnetic anomalies of importance were located in within the following grids; RTP640.grd (191 nT), RTP641.grd (425 nT), RTP642.grd (85 nT), RTP643 (329 nT, -688 nT), RTP739.grd (115 nT, -51 nT), RTP740 (156 nT, -135 nT), RTP741 (136 nT, -279 nT), RTP742 (99 nT, -201 nT), RTP743 (1323 nT, -632 nT), RTP744 (1470 nT, -836 nT), RTP843 (621 nT, -421 nT) and RTP844 (299 nT, -250).

Grids RTP643, RTP743, RTP744, RTP843 and RTP844 contain the strongest anomaly and reside in the same approximate location to northeast of the Subandean range with the exception of RTP643.
There is not one large anomaly but rather several irregularly shaped magnetic anomalies across this section of study area #3. The large positive and negative anomalies could be a reflection of deep basement material, but it seems peculiar that the anomalies would be so intense for deep magnetic objects if this is the case. Also, this region resides within the boundaries of a back-arc basin, which could mean that the extreme anomalies result from large amounts of basaltic material (with elevated magnetic content) existing in the lower portions of the crustal lithosphere. However, back-arc regions generally do not generate high volumes of melt. Magnetic data alone cannot decipher between lithologies. Instead seismic studies would need to be performed in order to better comprehend the crustal lithologies.

The rest of study area #3 produced only minor positive and negative magnetic anomalies. Much of the Interandean and Subandean zone are comprised of marine clastic and carbonate rocks, which could produce minor negative anomalies. Small positive anomalies could be attributed to the highly evolved igneous rocks contained within the Andes Mountains. Perhaps the felsic material in this region contains only minor amounts of magnetic material.

Table 10 displays each grid’s largest positive anomaly for U, Th and K (study areas #1 and #2 did not contain any U, Th or K grids). Potassium percentage for each grid failed to yield any outstanding anomalies. In fact the highest percentage found was 3.34 by grid POT845, which is only slightly larger than the crustal average of 2.59%. U and Th produced greater anomalies on the order of 10-20 their respective crustal averages of 2.7 ppm and 10 ppm. Nevertheless no grid produced high enough K, U and Th values to warrant further investigation.

<table>
<thead>
<tr>
<th>Grid #</th>
<th>U</th>
<th>Th</th>
<th>K</th>
</tr>
</thead>
<tbody>
<tr>
<td>*743</td>
<td>22</td>
<td>75</td>
<td>2.77</td>
</tr>
<tr>
<td>*744</td>
<td>14</td>
<td>118</td>
<td>2.08</td>
</tr>
<tr>
<td>*745</td>
<td>12</td>
<td>84</td>
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</tr>
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<td>30</td>
<td>2.37</td>
</tr>
<tr>
<td>*844</td>
<td>6</td>
<td>18</td>
<td>3.37</td>
</tr>
<tr>
<td>*845</td>
<td>5</td>
<td>9</td>
<td>3.34</td>
</tr>
</tbody>
</table>

Table 10. Highest U, Th and K values within particular grids.
5.3.3 Northern Chaco Plain

A major magnetic anomaly spans across the grids RTP947 and RTP948 of study area #4 (Figure 65). Magnetic readings reach as high as 1224 nT and as low as -611 nT. The grids run successively north-south so it is impossible to gain perspective on the lateral extent of this anomaly. The large anomaly may result from a large piece of highly magnetized basement material existing at shallow depth.

Figure 65. Arcmap™ image showing the location of study area #4. The red and yellow box corresponds to image 232-71.
Other dimensionally small magnetic anomalies occur within grids RTP949 RTP950 and RTP951. Grid RTP949 contains anomalies reaching as high and low as -424 nT and 264 nT. It appears that the dispersed negative anomalies are more intense than adjacent positive anomalies. The material contributing to the negative anomalies may be composed of sandstones and shales in the subsurface. Here basement material probably resides at greater depth, effectively contributing less to the positive anomalies.

Grid RTP950 contains a broad strongly positive anomaly in the center. It reaches values as high as 446 nT. A smaller, dimensionally, positive anomaly exists in the eastern section of the grid and reaches values as high as 619 nT. It is unclear as to how extensive these alternating positive anomalies are considering no magnetic information exists east or west of these grids. Increasing negative magnetic readings exist adjacent to the positive anomalies and are clearly associated with one another. Highly polarized shallow basement material may produce the magnetic values on the grids. Magnetic intensity appears to decrease within RTP951 compared to RTP950. Perhaps basement material exists at greater depths within grid RTP951.

U, Th and K grids produced concentrations that appeared to correlate with one another. Elevated U and Th regions coincided with elevated K regions and vice versa. U, Th, and K values reached as high as 19 ppm, 93 ppm and 6% respectively. The eastern half of each grid contain higher amounts of each elements compared to the western half. Fluvial bodies produced chemical values of almost zero for each element.

5.3.3 Northeastern Bolivia

Study area #5 (Figure 66) contains several GXF files with bad lines, making a complete analysis of this area difficult. Strong anomalies were virtually absent from the usable data files RTP052, RTP053, RTP055, RTP152, RTP153 and RTP154. The largest anomalies were found within grid RTP153 and reached values of -828 nT and 466 nT. Perhaps this area lacks large-scale magnetic anomalies, either because they don’t exist or near-surface features effectively disguise a deeper magnetic body’s response.
5.3.4 Eastern Bolivia (Laguna Concepcion and San Ignacio)

Large magnetic anomalies were found within the files RTP440 (2675 nT, -1299 nT), RTP540 (2701 nT, -1296 nT) and RTP543 (501 nT, -533 nT) from study area #6 (Figure 67). These large anomalies occurred adjacent to areas of minimal magnetic response. In all three cases the anomalies occurred at the edge of the respective grid, possibly introducing edge effect errors. However, if the anomalies are accurate then there are two major magnetic bodies within RTP440 and RTP540 (overlap of data) and within
RTP543. The anomaly overlapping RTP440 and RTP540 could be a shallowly intrusive young and highly magnetized igneous body, partially due to its small dimensions. Such a strong magnetic anomaly may indicate the igneous body is mafic, possibly gabbroic in composition.

According to a preliminary report by Sander Geophysics LTD. this anomaly has been named the Santa Teresita magnetic anomaly. British Mission and Geobol (Servicio Geologico de Bolivia) mapped minor amphibolite and feldspathised plagioclase-diopside calc-silicate material surrounding the intense anomaly, potentially indicating the presence of a skarn deposit associated with a mafic body. According to the report possible mineralization models for this anomaly could be the copper-gold mineralization associated with calc-silicate skarns such as the Duchess region, Mt. Isa, or gold mineralization associated with (remnantly magnetized) fluid alteration pipes such as Mt Leyshon or Charters Towers (note the gold mineralization at Mt Leyshon lies at the NE edge of the alteration system). The report also suggested the anomaly may arise, instead, in response to the presence of a carbonatite. These exist north of the Laguna Concepcion block, and are typified by a large magnetic response. They would be expected to have a low radiometrics response and the Santa Teresita anomaly does have a 'hole' in the radiometrics data (radiometric data from this area is absent in the dataset).

The remaining grids produced minor anomalies on the order of +/-50 nT to a maximum of +/-300 nT. Of the all the anomalies the negative ones appeared to be more intense, potentially indicating the presence of massive porous sedimentary units at depth.

K grids produced little anomalies over the study area. Most of the grid recorded K percentages around the crustal average of 2.59%. The highest recorded K values approached percentages greater than 8%.

Grid *447 produced the highest recorded K percentage of study area #6 at 8.1% and also contained elevated U values approaching 65 ppm. However the largest Th anomaly of all study areas occurred within grid THO447. Th was detected at an anomalous value of 861 ppm. Such high U and Th values detected at the same location possibly imply the presence of an extremely mature host rock (granitic pegmatite?) containing high amounts of rare earth elements. In general as U enrichment increases so too does Th enrichment. However, Th is approximately 86.1 times more abundant here than in average crustal
rocks compared to 24 times for U. Perhaps large quantities of thorianite minerals are present at the surface
that incorporated moderate amounts of uranium oxide within its mineral structure. This could account for
the relative over-abundance of Th compared to U.

Figure 67. Arcmap™ image showing the location of study area #6. The box corresponds to image 229-73.
From satellite imagery the location of the anomalous U, Th, and K region appears to have moderate topography (up 600 meter in elevation) and is of greater relief than its surroundings (up to 330 meters in elevation) (Figure 68). The highest U and Th readings occur along the flanks of the highest elevated area within the mountain range and, subsequently, decrease with increasing distance from the major anomaly. This can partly be explained by the immobility of Th and U. A river channel flowing to the west-northwest contains elevated U and Th, with respect to adjacent plains, with Th values only about 5 times greater than average crustal rocks (again testifying to Th high immobility). As mentioned earlier the mountain range must be composed of mature rocks, potentially granite pegmatitic or carbonatitic (possibly the Manoma carbonate complex) in composition and texture. If the mountain range is igneous nature then it appears magmatic compatibility issues caused the over abundance of Th compared to U. Considering both U and Th are large ion lithophile elements and rare earth elements that are only separately by 2 atomic numbers, the process of extreme Th magmatic preferential partitioning compared to U in this case is unclear.

According to the preliminary Sanders Geophysics’ LTD report carbonatite rocks north of Laguna Concepcion are typified by large magnetic responses accompanied by low radiometric counts. If this anomaly is in fact a carbonatite, then its’ magnetic (defined by an irregular negative response approaching -152 nT, potentially due to a lack of significant magnetite) and radiometric responses are completely opposite of what Sanders Geophysics expects. A second report supports findings of high radiometric counts and a minor negative magnetic response within this region. Interestingly the report refers to this anomaly as part of the Manoma carbonate complex. The discrepancy between Sander Geophysic’s second report and the observed magnetic and radiometric counts further exemplifies the high degree of geochemical variability and, most importantly, the lack of concrete understanding of carbonatite generation and evolution.

Other grids such as THO445 produced high Th and U values approaching 160 ppm and 22 ppm respectively. Every Th anomaly is found in conjunction with elevated U content. In most cases, but not all, Th enrichment is greater than U enrichment for a given area relative to crustal averages. It appears that a similar process of Th enrichment has occurred within the other grids relative to U, but at much small
scales compared to grid *447. For grids other than *447 dispersed geochemical soil and outcrops sampling should be considered in an attempt to determine lithology (hopefully to piece together a regional lithological map of the area for purpose of determining correlation between similar rock units and to gain perspective on geological process involved in the regional Th and U enrichments).

Figure 68. Google Earth™ image of a small isolated mountain range. The mountain range contains extremely high Th values coupled with moderately high U values.
6. Conclusions and Recommendations

After analyzing the dataset provided by Sinchi Wayra more questions were raised than were answered. However, considering only a small amount of Bolivia’s economic mineral potential has been exploited, this report provides a first order approach to locating mineral exploration targets. Of all the locations where any combination of geophysical, satellite and/or geochemical data exists approximately two sites contain economic mineral potential (Cachi Laguna and Tollocci), fourteen sites contain underdeveloped mineral potential (only five are discussed in this section) and an additional five sites require further investigation based solely either on ratio images or radiometric data (grid #447, image 232-74).

Geochemical sampling of outcrops, soils, float material, stream sediments and minor drilling from areas within and adjacent to the Bolivian Tin Belt reveal elevated combinations of As, Au, Bi, Sb, Ag, Sn, Cu, Pb, Zn, Sn or W predominantly associated with quartz veining, silicification and/or oxidation. Many of the identified deposits formed from epithermal polymetallic hydrothermal systems. These deposits contain significant sulfide/oxide minerals associated with Ag-Pb-Zn, Ag-Pb-Zn-Bi-Sb, Au-Ag-Pb-Bi-Sb-(As), Ag-Sb, Au-Bi-As or Au-Ag-Bi-As-Sb mineralization.

In the southern part of the Bolivian Tin Belt the host rocks are predominantly composed of felsic to intermediate porphyrytic and volcanic rocks. With the exception of Tollocci quartz veins contain much of the metal content and cut through domes, stocks and dikes. The quartz veins represent the youngest hydrothermal features based on cross-cutting relationships and form along major lines of weakness (structural trends) in the crust (faults and fractures). The structural trends tend to control the orientations of the veins, which usually run SE-NW. Evidence suggests that some of these vein systems could run continuously for more than a few kilometers in length. However metal grades tend to drop significantly where alteration shifts from moderate to high temperature potassium-rich zones (sericite) to low temperature propylitic (chlorite and epidote).
Many of the deposits in the southern Bolivian Tin Belt carry Ag as the primary economic metal. The vein hosted hydrothermal systems contain the association Au-Ag-Pb-Zn-Bi-Sb-(As)-(Cu), although Au, Zn, As, Cu and Sb can be highly variable. Argentiferous galena and/or sphalerite contains high grade Ag and, in some cases, may be auriferous as well. Cu is generally found in the sulfide chalcopyrite and the oxides malachite, azurite and cryscollia. In some veins systems Cu correlates strongly with Ag and may coexist with one another in the sulfide polybasite. There exists the small possibility that a few of the deposits may overly weak to moderately mineralized porphyry Cu systems. In essence, the Ag-Pb-Zn rich quartz veins may represent the top of a porphyry Cu system. More work is needed to confirm or deny this possibility. Sn and W are relatively absent to the south. This may be partially due to the felsic nature of the igneous source rocks or due to the geochemical makeup of the underlying mantle and base of the crust.

In the northern part of the Bolivian Tin Belt igneous rocks become less abundant at the surface as the landscape is dominated by clastic sedimentary rocks composed of siltstone, mudstone, sandstone, greywacke, conglomerate and quartzite. Quartz veins host some of the metal sulfides and oxides in the deposits, but are less abundant compared to the south. Instead much of the metals are deposited along fractures and/or faults with or without quartz. Mineralization is associated with oxidation along abundant faults and fractures in the clastic rocks. However, similar to the deposits to the south, major lines of weakness in the crust provide avenues for fluid transport and structurally control the orientation of mineralization. Major fault orientations include two dominant structural trends; SE-NW and E-W.

Most of the northern deposits contain the association Au-Ag-As or Ag-Pb-Zn-Sn-As-(Bi)-(Sb). Au is almost always associated with As, occasionally associated with Ag, Bi and Sb and rarely, if ever, associated with Sn. Au also forms a strong mineral belt that strikes approximately 330º NW and runs for more than 50 km in length. Sn is associated with Ag, Pb and Zn and less often with W despite the fact that many of the deposits to the north are up to 50 km away from the nearest igneous intrusion. The sedimentary hosted deposits may overly intrusions residing at 1 to 2 km depth and, subsequently, may represent the upper portion of these hydrothermal systems.

In the Western Cordillera and Altiplano of Bolivia few mineral deposits were identified. The Altiplano region is known for vast number of salt flats that contain industrial minerals such as halite that
are not of prime interest in this study. West of the Aliplano, close to the Chilean-Bolivian and Peruvian-Bolivian borders, most of the rocks are comprised of young intermediate volcanics. Many of the volcanic features contain moderate to strong alteration that is not associated with significant mineralization. Where mineralization occurs Ag emerges as the primary metal of interest. Ag is generally associated with Sb and other metals such as Pb and Zn.

Geochemical analysis of eastern Bolivia produced little in the way of potential economic mineralization. Only one region occupying the northern section of image 228.73 could warrant future economic consideration. Mineralization primarily is of the Ag-Pb-Zn type. However, soil data was only minimally analyzed and, therefore, should be analyzed further to see if less obvious anomalies exist.

Airborne geophysical data produce a few magnetic and only one radiometric anomaly. No significant anomalies were found within the Eastern Cordillera of the Andes Mountains. Only one major magnetic and radiometric anomaly was found in the eastern Santa Cruz region; the magnetic anomaly associated with a shallow intrusive and the radiometric anomaly associated with a carbonatite.

### 6.1 Cachi Laguna

Perhaps the best location to explore for mineral potential, Cachi Laguna has produced some favorable results. The property is located approximately 19 km east of the Chilean border in the southern end of the Western Cordillera of Bolivia. Drill core samples were obtained from the flanks of the Cachi Laguna volcanic center and geochemical analysis revealed the presence of significant Ag along with moderate Au and Sb and minor Pb, Zn, As, Bi and Hg within a high-sulfidation epithermal type deposit. High grade Ag-Sb mineralization originates from within strongly silicified dacitic volcanic and porphyritic rocks, while high grade Au mineralization is hosted by strongly silicified rocks as well by vuggy leached rocks. Advanced argillic alteration (quartz-alunite) occurs along the margins of vuggy silica alteration, in which the advanced argillic zones only contain high grade Ag (alteration zone covers an area
approximately 10^2 km). Pb mineralization is sporadic throughout the argillized and silicified areas, but is to be relatively weak compared to Ag.

Au-Ag-Sb enrichment appears to occur primarily at shallow depths in conjunction with abundant hypogene stibnite and sulphosalts. Drill core samples from 0-30 meters depth contained an average Ag grade 25% higher than the samples at depths between 30-100 meters (highest surface Ag grade = 13,481 ppm). While supergene processes likely accounted for some of the near surface Ag enrichment, most of the grade disparity between surface and at depth, in general, originates from a difference in degree of silicification. On the other hand high grade Ag mineralization at the surface is sometimes associated with hypogene stibnite and bismuthinite. This could imply that hypogene Ag may exist at depth in areas previously undrilled. Further drilling and geophysical surveying is recommended to define the vertical extent of potential Ag mineralization.

Unlike Ag, Au is not a driver for mining, but could later prove to be a valuable byproduct of Ag mining at Cachi Laguna. Local Au grades can reach as high as 215 ppm in adjacent leached zones that contain moderate Ag grades. In areas of high silicification Au is almost always associated with significant Ag mineralization.

A rudimentary block model was created to estimate the Au and Ag resource at Cachi Laguna. Preliminary results concluded that approximately 108,673 ounces of Au and 28,668,288 ounces of Ag exist at Cachi Laguna with another 20,000 ounces of Au and 20,000,000 ounces of Ag possible. Au and Ag average grades were 0.553 ppm and 67.26 ppm respectively. No Sb resource was calculated due to time constraints. However, Sb could later add to the value of the Cachi Laguna property and should be evaluated further in the process of potential mine development.

6.2 Tollocci

Located approximately 15 km west of Cerro Rico de Potosi, Tollocci resides within the Bolivian Tin Belt and in the eastern half of the Los Frailes-Kari Kari volcanic field. Its rock units, which include
fresh rhyolite, diatreme breccia, sanidine dacite, intracaldera breccia, tuffaceous rhyolite, felsic porphyrytic rocks, correlate well with other areas of known Ag-Sn-Zn mineralization (Cerro Rico, Porco and Chachacomiri), making it a good target for advanced exploration.

A broad zone of argillic, advanced argillic (quartz-alunite) and silicification has occurred over an area containing fresh rhyolite, diatreme breccia, sanidine dacite, intra-caldera breccia and banded rhyolite. Ag is primarily hosted in strongly silicified rocks that tend to form Mantos type bodies. The core of these silicified areas is generally accompanied by high sulfide content, which contains the high grade Ag. Along the margins of silicification, argillization of the rocks has been identified. In general the contact between the silicified and argillized rocks is a hard boundary, although moderate Ag mineralization can extent up to a few meters into the argillic zone. The argillized areas tend to host the bulk of the Zn mineralization.

Resistivity and IP studies show zones of anomalously low and high resistivity and zones of remarkably high IP values, indicating sulfidation of up to 16%. Within the zone of alteration three main areas have revealed potential economic Ag grades that include Juchuy Tollocci (5.6 Mt @ 133 ppm), Manto Español (619,000 t @ 169 ppm) and an unnamed mantos body (1.4 Mt @ 139 ppm). In total 7 Mt @ 134 ppm Ag have been defined.

Missing soil and rock geochemical data have been written about in an Emicruz report. According to the report the northern section of the study area (Error! Reference source not found.) contains reasonably high grades of Zn adjacent to high grade Ag. Only minimal sampling has occurred in this area, so it is highly recommended that further geochemical (soil and drill) and geophysical (IP survey) be conducted to further investigate grade, tonnage, and extent of Ag and Zn in this area.

### 6.3 Cerro Isca Isca

Cerro Isca Isca is located approximately 5 km west of the town Isca Isca in the Eastern Cordillera. The property covers a large area of epithermal polymetallic veins. High grade values for metals such as Au, Ag, Pb, Cu, Sn, W, Co, Cd, Bi, As and Sb have been found in the quartz veins that cut shales, siltstones,
hornfels and granodiorites. Most of the quartz veins strike 90º E, indicating a potential structurally controlled trend. Au reaches as high as 11.7 ppm, Ag at 1395 ppm, Pb at 1.0% (over limit), Cu at 10.8%, Sn at 0.2% (over limit), W at 0.17%, Co at 0.51%, Cd at 0.16%, Bi at 0.2% (over limit), As at 1.0% (over limit) and Sb at 0.2% (over limit). The bulk of the high grades come from As followed by Bi and Au. Although much of the surface is oxidized, hypogene minerals begin to appear at just a few tens of meters depth. Most of the sulfides identified are either pyrite or arsenopyrite.

While quartz veins contain appreciable amounts of As so too do the clastic rocks and granodiorite rocks. Metal grades reach as high as 46.27 ppm for Au, 72.8 ppm for Ag, 1.0% for Pb (over limit), 6.8% for Cu, 0.2% for Sn (over limit), 0.2% for W (over limit), 0.2% for Bi (over limit), 1.0% for As (over limit) and 0.16% for Sb. It is likely that the high grades found in the clastic rocks and granodiorite rocks are due to either partial dissemination or fracture controlled mineralization. No fracture information is present, which makes it difficult to discern the truth about mineralization in the clastic rocks and granodiorite rocks.

Future work is recommended for the continuing exploitation of W, Sn, Pb, Sb and As. Other metals that could be exploited include Au, Cu and Bi. Mapping and soil sampling is recommended to determine the continuity of the veins and to further the understanding of the geological relationships between the veins and host rocks.

6.4 Omoxa

Omoxa is located approximately 100 km northwest of Lake Poopo in the Eastern Cordillera. The northern section of the property is primarily composed of sandstone and quartzite, while the southern section is a mixture of dacitic igneous rocks and sandstone. The general strike direction of the sedimentary beds ranges from approximately 300º to 330º NW. This is perpendicular to the direction of thrusting in the Eastern Cordillera of central Bolivia. Faulting and fracturing, however, vary much more in terms of strike direction, but appear to be dominated by two primary strike directions; 30º NE and 290º NW. With two primary fault and fracture strike directions roughly perpendicular to one another the potential for
intersecting faults appears to be high. Intersecting faults coupled with significant alteration in the area makes omoxa an interesting target for exploration.

Despite the likelihood for poor host rocks in the area, omoxa is still a good exploration target for Au, Ag, Bi, As, and Sb. The high grade Au and moderate Ag, Bi, As and Sb from fault breccias indicate ore fluids were moving through and depositing metals along these fault controlled breccia zones. Although little to no mineralization exists in the rocks surrounding the mineralized faults there still exist the possibility of fracture controlled mineralization at depth. If no significant mineralization exists at depth in the surrounding rocks, the surface indicated high grade oxide Au in the faults could still be mined and heap leached without the added cost of building and operating a sulfide processing facility.

More surface mapping and sampling is needed to better define the extent of Au and Ag grades contained within the fault breccias. Soil sampling is also recommended to determine where metals have bled out of mineralized structures. If drilling commenced perpendicular to the strike of these faults, then it may yield a better three-dimensional picture of the geology and mineralization.

6.5 Colavi

Colavi is located approximately 35 km NW from the city of Potosi in the Eastern Cordillera of Bolivia. It resides to the east of the Las Frailes volcanic field by up to a few tens of kilometers. Similar to other sections of the Eastern Cordillera, Ordovician and Silurian sediments dominate the landscape (Figure 15). Igneous rocks also exist throughout the area in the form of Tertiary felsic to intermediate volcanics. Colavi has been known to miners for quite a while as small scale mining has taken place in the past within and around the Colavi area.

Much of the rocks in the Colavi area are cut by faults and quartz veins. Veining appears to cut all rock types, implying it is younger than all the exposed rocks. The quartz veins are of the polymetallic type, containing anomalous quantities of Ag, Pb, Zn, Cu, Sn, Bi, As, Sb, Fe and Mn. Much of the high grade Ag occurs either in or within close proximity to quartz veins. The high grade Ag that is found in close
proximity to the veins is primarily hosted in sandstone. Much of the abundant Ag is found where the sandstone is heavily oxidized with or without any silicification. The sandstone beds were likely porous enough to allow hydrothermal fluids to pass through them and deposit Ag, while the volcanic units likely lack the necessary porosity. The lone exception may be the porphyritic rocks where sporadic high grade Ag, Pb and Zn have been reported.

Future work in the Colavi area should include surface mapping of the veins and faults. Quartz veining may, in fact, follow the orientations of various fault zones. The polymetallic veins contain the highest metal grades and should be located as well as mapped, particularly within the sandstone beds. Potential dissemination into the sandstone units opens up the possibility for finding near surface high tonnage ore.

6.6 San Florencio

San Florencio is located on the border between the states of Potosi and Oruro, approximately 4 km SW of the town of Chaquilla. Approximately 753 rock samples were collected over an area approximately equal to 6.7 km². San Florencio resides in the Eastern Cordillera of the Bolivian Andes and is dominated by clastic sedimentary rocks (Figure 19).

Based on surface rock sampling anomalous Au, Ag, Pb, Zn and Sn mineralization has been identified within the altered areas of San Florencio. Metal contents reach grades of up to 0.75 ppm Au, 201 ppm Ag, 1.0% Pb (over limit), 1.0% Zn (over limit) and 17.4% Sn. Although Au and Zn mineralization have been identified, surface sampling generally revealed only sparse anomalies. Ag, Pb and Sn mineralization, on the other hand, is widespread and abundant. Much of the moderate to high metal grades are hosted by the massively bedded sandstone. While some mineralization occurs within the igneous rocks, the dacite and rhyolite rocks are generally unmineralized and may represent a late stage, post mineral subvolcanic to volcanic event.
The Sn zone varies, in terms of alteration, from the rest of the property. While much of the property is dominated by argillization the fracture zone is dominated by silicification and moderate to high temperature sericite. The fact that Sn mineralization is found within the highly fractured sandstone zone that exhibits distinct alteration relative to the rest of the property indicates that Sn formed within a structurally and mineralogically unique setting. In terms of exploration these characteristics should be taken into account when assessing potential Sn targets.

Adjacent to the Sn zone is an extensive area of argillized sandstone. In contrast to the sandstone within the Sn zone the argillized sandstone contains only minor silicification with widespread Ag and Pb mineralization. Ag and Pb are generally low grade but can reach grades of up to 201 ppm and 1.0% (over limit) respectively. Au mineralization is also present, but extremely sparse.

A total of seven holes were drilled in 1997 within San Florencio, but contained no log data. Figure 20 displays the collar locations and the approximate 2D orientation of the drill holes. Each drill hole was drilled to the southwest and none were drilled through the surface indicated Sn zone. However, significant Zn mineralization was encountered to the west of the Sn zone that includes 247 meters of 1.12% Zn (Table 2). A total of four drill holes hit extensive Zn mineralization adjacent to the Sn zone. All of the moderate to high grade Zn was encountered at a distance of at least 100m down the hole (all the holes were drilled at approximately 60º). Coupled with the fact that the Zn grades at the collar were generally below 100 ppm explains the reason for the lack of surface indicated Zn mineralization based on rock chip sampling.

Overall San Florencio has excellent mineral potential. The surface indicated Sn zone contains an average of 0.62% Sn that locally reaches grades of up to 2.26%. No drilling has occurred in this region leaving the possibility for future exploration work. A resistivity survey is recommended to determine the areas of high resistivity that may correspond to a high degree of silicification. The silicified rocks in the Sn zone contain the high grades.

The other major exploration target resides off the west of the Sn zone. Moderate Zn grades occur of large intervals and were encountered by all of the drilling in the north. This area has the potential to be a large Zn based on the drilling. Infill drilling will need to occur in order to better define the broad zone of
Zn mineralization. It is possible that Zn occurs in highly argillized rocks. A resistively survey is recommended in order to determine areas of intense argillization and open spaced breccias zones. Ag also occurs in the same vicinity as Zn and the low grades could make the Zn target more economically attractive.

6.7 Berenguela

Berenguela is located approximately 150 km southwest of the city of La Paz and 30 km east of the Peruvian border. Much of the region is dominated by Tertiary igneous rocks, although significant amounts of Tertiary sedimentary rocks persist throughout the region. Quartz veining on the property is abundant and is considered polymetallic. The veins contain anomalously high values of Ag, Pb, Zn, Cu, Cd, Mn and As. However, the metal grades are not consistent throughout the veins. For example while grades of 2540 ppm Ag, 33.2% Pb, 45.1% Zn, 53.5% Cu, 3.0% Cd, 2.0% Mn and 1.86% As have been reported all metals mentioned fell below detection limit in multiple other veins. This may or may not be due to sporadic and inconsistent mineralization in the quartz veins. Another possibility is that some of the veins were selectively sampled, leading to such high metal grades.

Another type of Cu mineralization found on the property exists in the region known as Anaconda. Much of the Cu grade is located in and adjacent to the faulted contact between the sandstone and diorite porphyry. Cu grades in the fault breccia reach as high as 11.1% and are consistently well mineralized. The surrounding sandstone and adjacent conglomerate units host good Cu grades, but less mineralized than the fault zone. Cu grades in the sandstone and conglomerate units reach as high as 2.2% and 4.5% respectively. Common to all rocks units and the fault zone is the presence of Cu oxides and low Bi, As and Sb grades. Malachite is the most abundant Cu oxide present, although appreciable quantities of chrysocolla have been reported. Unlike the rock units in Anaconda, the fault breccia contains chalcocite, which explains the relatively higher Cu grades. The preexisting fault zone (formed in response to depressurization of the magma chamber?) may have acted as a conduit for Cu-bearing fluids to ascend and
later descend through. Descending Cu-bearing reducing fluids deposited chalcocite within the fault breccia at shallow levels. The porous sandstone and conglomerate units in the vicinity acted as good hosts and allowed ascending fluids to penetrate the respective matricies and/or along fractures.

Bordering the diorite porphyry to the west, in the heart of Berenguela, the sandstone beds may be a good host rock for Ag, Pb and Zn. The sandstone beds are cut by mineralized and non-mineralized normal faults carrying grades of up to 1509 ppm Ag, 10.3% Pb and 0.4% Zn. Veining and faulting in the sandstone vary in orientation, but generally strike either E-W or NW-SE. The faults likely provided a good pathway for fluid movement through and dispersion into the highly fractured sandstone. Quartz veins followed the paths of the preexisting structures, which explains their similar orientations.

Surface sampling from Tatitu Kkollu indicates moderate grades exist for Ag, Pb and Zn with sparse Au. Most of the Ag, Pb, Zn and Au grades are hosted in the volcaniclastic unit. The silicified volcaniclastic rocks host much of the Ag grade with or without low grade Zn. However, in the argillized volcaniclastic rocks, Zn is moderate (occasionally high grade) and is generally not associated with Ag mineralization. The contact between silicified and an argillized volcaniclastic rocks is a hard boundary. While the better Zn grades in the silicified rocks are found close to the silicified-argillized contact and the better Ag grades are found in the argillized rocks close to the silicified-argillized contact a hard boundary exists between the two. This is due to the fact that Zn and Ag mineralization away from the contact diminishes rapidly within silicified and argillized volcaniclastic rocks respectively. A resistively survey is needed to better determine the subsurface alteration at Tatitu Kkollu. This would aid in target delineation for the separate Ag and Zn domains.

6.8 Grid *447

Grid *447 has produced a large Th anomaly, approaching 861 ppm, centered on the coordinates 745146E, 8282688N. While U enrichment is present, up to 65 ppm, it is not as intense or prevalent. According to a preliminary Sanders Geophysics LTD report the observed Th and U anomalies may occur
within the Manoma carbonatite complex. Due to the minor negative magnetic response it is likely the carbonatite is not magnetite-apatite rich. In terms of economic potential this area may or may not contain significant amounts of niobium-tantalum, zirconium-hafnium, iron-titanium-vanadium, uranium-thorium (observed) and industrial minerals such as apatite, vermiculite, Cu-bearing minerals (observed from several locations in Africa) and barite (Guilbert and Park, 1986). Soil and outcrop geochemical sampling is recommended for the entire local topographic high encompassing elevated Th and U counts. If Cu or other sulfide-associated elements are present then a comprehensive IP survey is also recommended for this area for the purpose of determining the extent of sulfidation.

Some geologists believe carbonatites can be associated with kimberlite pipes. Geologically young carbonatites appear to be related to rift environments; they occur with kimberlite associates, generally within rifted cratonic interiors and with the suggestion of deep crustal or upper mantle processes involving carbonatitic liquid separation and injection, or some other form of mantle degassing (Guilbert and Park, 1986). No age dates from this region are currently known, so it is unclear if this anomalous zone is the product of the extensive Cambrian-Ordovician rifting event. However carbonatite generation and evolution is highly speculative and it would be a mere guess to state that there is a kimberlite pipe associated with this carbonatite. The absence of a definite magnetic anomaly certainly does not imply the presence of a kimberlite pipe, but as with carbonatites, the magnetic response is highly variable. Nevertheless further investigation into the presence of kimberlite pipes is lightly recommended.

6.9 Image 232-74

Solely based on the Landsat™ image 232-74 there are at least four areas that deserve consideration. The first area is centered on the point 781875N, 851741E within UTM zone 19. On a geologic map this igneous feature is defined as comprising Tertiary undifferentiated intrusive material. The igneous feature is rather large at approximately 11 km in diameter and its geomorphology not only resembles Venus’s pancake/tick volcanic features, but also compares rather well despite being only about
half the width. In other words, this igneous body may be an Earth analogue to Venus’s strange volcanic features.

According to satellite imagery this feature appears to only contain surficial clays within the numerous lakes that occupy the region. On the other hand large high concentrations of iron have also been detected here. While surficial alteration appears to be nonexistent further investigation into the petrology of the region is recommended. The southwest corner of this igneous body has been mined while only two mines have been established throughout the rest of the feature. It appears little is known about the vast majority of this area. The western half of the feature is a good place to start conducting field work, considering a decent number of east-west trending faults penetrate this region. These fault locations probably provide the best chances for finding economic mineral potential.

The other three locations that deserve consideration are located at 774953E, 7735657N; 757124E, 7796893N 808505E and 7684427N. The first two locations have moderate iron contents with minor clay material present. The last location contains high surficial iron content and appears to be volcanic based on its geomorphology. These features do contain high adjacent clay areas, but appear to be confined within river channels or lake beds. Based on satellite imagery alone it is extremely difficult to located possible areas of alteration either because they do not exist, they do not crop out at the surface or are too small to be detected by band ratioing. Nevertheless, the regions of high iron content may prove to contain igneous material that may contain economic iron minerals, rare earth elements and/or other precious metals such as gold.
Appendix A

Useable Data Files

CD: Data B250 Bolivia
  LA PAZ FOLDER
    DRILL FOLDER → ANALYSIS.DBF, ANALYSIS.DBF, BOOO*.DBF, BATCH083.DBF, CODELIST.DBF, COLLAR.DBF, LAB_REP.DBF, LAB_RESU.DBF, LABBACK.DBF, LABNUMBE.DBF, LABRES.DBF, LABRESTO.DBF, LOGDATA.DBF, OOO.DBF, ORDEN.DBF, PO2.DBF, SAMPLE1.DBF, SAMPLES.DBF, STATIST.DBF, STDLIMIT.DBF, SUMMARIO.DBF, TRAN3.DBF
    CARIMBOS FOLDER → BASE3.DWG, BASE4.DWG
    CIRUG → BRCURG*.DBF, LABRES*.DBF, NBAT.DBF, URG01-5.DBF
    CONSULTA FOLDER → BER*, BRC*
    GEOPHYS → RHIDIR → RTZPCAM*
    GEOQUIM FOLDER → BORRAR*.DBF, CODELIST.DBF, COLAVII.DBF, EXPOMEMO.TXT, LAB_REP.DBF, LABBACK.DBF, labres.DBF, MALO.DBF, OMOXA, P.DBF, PROMEDIO.DBF, PTGEAON, RXALTMIN.DBF, RXDESCRI.DBF, RXSTRUCT.DBF, SIERRA.DBF, SNCOLVI.DBF, SOILS.DBF
    POTOSI FOLDER
      DRILL FOLDER → ANALYSIS.DBF, CODELIST.DBF, COLLAR.DBF, LAB_REP.DBF, LAB_RESU.DBF, LOGDATA.DBF, LABRES.DBF, NOMBRE.DBF, POXOCIRL.DBF, SAMPLES.DBF
      GEOQUIMI FOLDER → ALISCA, BASESL3.DBF, BATCH*, COLAVII.DBF, GEOCACH*.*DBF, LAB_REP.DBF, LAB_RESU.DBF, LABBACK.DBF, LABRESTO.DBF, RXAL*.DBF, SAMPLES.DBF
    SANTA CRUZ FOLDER
      DRILL FOLDER → 73.DBF, ANALYSIS.DBF, CODELIST.DBF, COLLAR.DBF, LAB_REP.DBF, LAB_RESU.DBF, LABBACK.DBF, LABRES.DBF, LABRESTO.DBF, LOGDATA.DBF, OOO.DBF, RESU.DBF, SAMPLES.DBF, STDLIMIT.DBF, TRAN3.DBF
      GEOQUIMI FOLDER → ANALYSIS.DBF, CODELIST.DBF, LAB_REP.DBF, LABBACK.DBF, LABNUMBRE.DBF, LABRES.DBF, RXAL*.DBF, SAMPLES.DBF, SOILS.DBF, STDLIMIT.DBF

CD: Anexos Comsur
  Cachi Laguna → BATCH*, COORD1, DDHPLAN.DXF, EAC*, ROAD*
    RESOURCE.DOS
    DATGEO → MANOLO*.DBF
    ESTANDA → CLLS
    POZOS → H1.SUR, ROCK.DES
  ISCA ISCA → ISCA
  TUCAVACA → CLR*.DBF, LOCATION.WK1

CD: Precambrian Comsur
  PRECAMBRICO
    ALL DWG FILES

CD: General Comsur
  GENERAL_PROYECTOS
EPE → EPE*.DWG

CD: Binary Grids in Geosoft Format
GSFT → G*.GRD
GXF → ALL GXF FILES

CD: Binary GAIDS in Geosoft Format
GRIDS
GSFT → ALL GRD FILES
GXF → ALL GXF FILES

CD: 7 FINAL REPORT
WORD → SGL*, FIG-WRD, RPT-WRD

CD: 11, 12
ddip
DRAPE → ALL GRD FILES
SLICE → ALL GRD FILES
MAG → ALL GRD FILES

CD: 13, 14 → ALL GRD FILES, T*.IP*, T*.DAT

CD: 15, 16
DCT → ALL GXF FILES
GRIDMAG → ALL GXF FILES
GRIPSPEC → ALL GXF FILES
LASPETAS → ALL GXF FILES
SIGNACIO → ALL GXF FILES

CD: 17
ELPUTENTE
MAG → ALL GRD FILES
RADS → ALL GRD FILES
TOPO → ALL GRD FILES

LASPETAS
DCT → ALL GRD FILES
FVD → ALL GRD FILES
RADS → ALL GRD FILES
RTP → ALL GRD FILES
SVD → ALL GRD FILES
SVD2 → ALL GRD FILES
TMI → ALL GRD FILES
TOPO → ALL GRD FILES
UTC → ALL GRD FILES

RIOBLANC
MAG → ALL GRD FILES
RADS → ALL GRD FILES
TOPO → ALL GRD FILES

SIGNACIO
DCT → ALL GRD FILES
FVD → ALL GRD FILES
RADS → ALL GRD FILES
RTP → ALL GRD FILES
SVD → ALL GRD FILES
TMI → ALL GRD FILES
TOPO → ALL GRD FILES
UTC → ALL GRD FILES

CD: 18
GRIDS
ELPUENTE
MAG → ALL GRD FILES
RADS → ALL GRD FILES
TOPO → ALL GRD FILES
LAS PETAS
DCT → ALL GRD FILES
FVD → ALL GRD FILES
RADS → ALL GRD FILES
RTP → ALL GRD FILES
SVD → ALL GRD FILES
SVD2 → ALL GRD FILES
TMI → ALL GRD FILES
TOPO → ALL GRD FILES
UTC → ALL GRD FILES
RIOBLANC
MAG → ALL GRD FILES
RADS → ALL GRD FILES
TOPO → ALL GRD FILES
SIGNACIO
DCT → ALL GRD FILES
FVD → ALL GRD FILES
RADS → ALL GRD FILES
RTP → ALL GRD FILES
SVD → ALL GRD FILES
TMI → ALL GRD FILES
TOPO → ALL GRD FILES
UTC → ALL GRD FILES

CD: 19
sansim 1
MAG
GRIDDATA → ALL GXF FILES
TOPO → ALL GXF FILES

CD: 20
sansim2
GRIDDATA → ALL GXF FILES

CD: 22
sansim3
MAG
LAS-PET
DCT → ALL GXF FILES
FVD → ALL GXF FILES
RTP → ALL GXF FILES
SVD → ALL GXF FILES
TMI → ALL GXF FILES
UTC → ALL GXF FILES
LASPETAS → ALL GXF FILES
SAN-IGN
  DCT → ALL GXF FILES
  FVD → ALL GXF FILES
  RTP → ALL GXF FILES
  SVD → ALL GXF FILES
  TMI → ALL GXF FILES
  UTC → ALL GXF FILES
SIGNACIO → ALL GXF FILES

CD: 23
ElPuente
GRIDMAG → ALL GXF FILES
GRIDSPEC → ALL GXF FILES
Rioblanco
  MAG
  GRIDS → ALL GXF FILES
  SPEC
  GRIDS → ALL GXF FILES
  TOPO
  GRIDS → ALL GXF FILES
Sigpeta2
  DCT → ALL GXF FILES
  FVD → ALL GXF FILES
  RTP → ALL GXF FILES
  SVD → ALL GXF FILES
  TMI → ALL GXF FILES
  UTC → ALL GXF FILES
Sigpeta3
  DCT → ALL GXF FILES
  LASPETAS → ALL GXF FILES
  SIGNACIO → ALL GXF FILES

CD: 24
  DCT → ALL GXF FILES
  FVD → ALL GXF FILES
  RTP → ALL GXF FILES
  SVD → ALL GXF FILES
  TMI → ALL GXF FILES
  UTC → ALL GXF FILES

CD: 25
  MAG
  GRIDS → ALL GXF FILES
  SPEC
  GRIDS → ALL GXF FILES
  TOPO
  GRIDS → ALL GXF FILES

CD: 28
TOLLOCCI REPORT
Figure1AND2

FIGURE1.DWG, IMAGE.DWG

GEOPHYSICS

1992

T*.IP*

MAPSDWG

MAP*.DWG

MMDAT

GEOLOGIA.DAT, COLLAR.DAT, SURVEY.DAT

CD: 29

ALL XYZ FILES

CD: 227_73_17

227_73_17.rrd

CD: 228row73

228row73.rrd

CD: 229_74

229_74.rrd

CD: 231_74

231_74.rrd

CD: 232row71

232row71.rrd

CD: tm232_74_051186

tm232_74_051186.rrd
References


Schneider and others. – 1992.- “Investigaciones Geoquímicas de Reconocimiento en en Departamento de Potosí”.- En: “Prospección y Exploración de Metales Básicos y Preciosos en el Departamento de Potosí, Bolivia”. Boletín del Servicio Geológico de Bolivia No. 5 (Especial).


UNAVCO Brochure Online, UNAVCO community meeting, 1998.