



MINERAL RESOURCES AND ENERGETIC DIRECTION

METALLOGENY PROGRAM

GE-24 PROJECT

**"Evaluation of Ore Deposits Potential
in the Andahuaylas – Yauri Batholith"**



Malachite occurrences (Morosayhuasi cluster)

TECHNICAL SCIENTIFIC REPORT

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ABSTRACT

INGEMMET through its Resources Mineral and Energy Direction – Metallogenic Program, signed an international cooperation agreement with the Korean Geological Survey (KIGAM) with the purpose of evaluating the ore deposits potential in the Andahuaylas – Yauri Batholith. This investigation includes metallogenetic interpretations using geochronological, isotopic, petromineralogy, structural studies, as well as geochemistry of rocks and sediments.

The importance of this area has increased over the years, during which many exploration works were carried out and consequently, many mineral occurrences have been discovered. Considered now as a probable extension of some copper belts of Chile (Perelló et al., 2003); nearly 70% of the area has been granted as mining concessions to different mining companies. Initially, this was considered exclusively a Fe-rich zone, but later on more detailed studies came to the conclusion that it hosts a series of ore deposits related to Cu – Au – Mo porphyry systems.

The international cooperation project lasted approximately 9 months, and included three field trips. During this period, mines, projects, prospects and potential areas free from mining claims were evaluated. The Andahuaylas - Batholith domain was divided into two study subzones, known as "A" and "B". One of the main areas in the subzone "A" was Cotabambas, where a series of porphyry deposits are located and are known collectively as the Cotabamba cluster. In the surroundings of this cluster, the Colca area was recognized, which has some potential to host an ore deposit. The geologic features are very similar to those of the Cotabambas cluster and small outcrops of malachite along fractures can be observed.

Several mineral occurrences were visited in zone B, such as: Angostura, Santa Rosa de Virundo, Yuringa, Atacancha, San Diego, Lahuahi, Jara Jara, Utupara and the surrounding areas of Las Bambas. Within this subzone, the Jalaoca area was recognized as an important potential area. This is located about 8 Km west from the Mollebamba city, very close to the inactive mines of San Diego and Lahuani. Polymetallic vein-type mineralization (quartz – molybdenite – hematite – chalcopyrite – bornite and galena) has been identified, as well as stockwork structures with pyrite and chalcopyrite probable related to porphyry deposits.

Another interesting area in the subzone "B" was Supamarca. This occurrence is located on the left side of the Abancay – Andahuaylas road. Copper sulphide mineralization and hematite in thin

laminates associated with siliciclastic rocks such as the sandstones of Muñani Formation (Upper Cretaceous – Paleocene) have been identified. These occurrences share some common features with such copper occurrences in red beds in the eastern sector of the Andahuaylas – Yauri Batholith.

This document presents new geochemical interpretations based on geochemical analysis of rocks and stream sediments. Geochemical graphic representation of major and trace elements give us an idea about the type of magmatism developed in the area and its associated potential. Isovaloric maps of stream sediments confirm the potential that some areas.

Interpretation of the data that polished and thin sections offer, confirm the type of rock and magmatism in the area of study. Finally, using the isotopic data collected from different studies it related the isotopic signatures with the expected tonnage for some porphyry deposits.

In this investigation, samples were collected from the Cotabambas cluster for isotopic and geochronology studies. Those samples are being currently analyzed at KIGAM laboratories (Korea).

This INGEMMET and KIGAM joint work tries to gather all the information related to the Andahuaylas – Yauri Batholith, and to update the existing geological data with the new data obtained from the field and office work, with the final purpose of providing exploration companies a new regional tool that will help them to better conduct their exploration campaigns.

INTRODUCTION

The origin and evolution of mineral deposits in Peru are related to a series of magmatic events, many of them are associated to subduction processes that take place in the Peru-Chile trench. One important pulse of this magmatic activity is represented by the voluminous intrusive rocks that comprise the Andahuaylas-Yauri batholith.

Important research has been conducted in this batholithic domain, Perelló et al., (2003, 2004), Carlier et al., (1989), Bonhomme & Carlier (1990) stand out among them. The general conclusion of all these investigations highlights the great potential of the Andahuaylas-Yauri batholith.

This belt is located between the Western Cordillera and the Altiplano of the Ayacucho, Cusco and Puno regions. The belt is bounded on the north by a regional structure known as the Abancay deflection, and on the east by the Urcos-Sicuani-Ayaviri fault system (Carlotto, 1998). The structural controls of the southern and western parts are difficult to interpret because the Miocene volcanic cover hides any pre-Miocene structural feature. These faults are thought to have been the boundaries of a tecto-sedimentary basin that controlled the Mesozoic sedimentation, generally composed of limestone (Albian–Turonian Ferrobamba Formation), and siliciclastic rocks (Jurassic–Cretaceous Yura Formation, and the Altiplano Mara Formation). (Perelló et al., 2003).

More than two dozen mining districts are located to the west, south and southwest of Cusco, defining an elongated province that extends over 300 km from Andahuaylas in the NW to the SE in Yauri, covering an approximate area of 25 000 square km. (Bellido & DeMontreuil, 1972).

From a geological point of view, the intrusive rocks have the greatest economic potential. Commonly known as the Andahuaylas-Yauri batholith (Carlier et al., 1989; Bonhomme y Carlier, 1990), moderately differentiated, these rocks have shown a strong affiliation with porphyry Cu-Au-Mo, skarn Fe-Cu deposits (Perelló et al., 2003), and Au veins in sedimentary rocks. Spatial and temporal correlations suggest that the batholith is related to mineral occurrences, with ages ranging from 48 to 30 m.y. (Carlotto, 1998)

A number of mineral occurrences have been recognized in this sector, but for a better understanding, they have been named in groups or clusters, which contain more than one ore

deposit with geological features that indicate that they are closely interrelated. For example: Tintaya Cluster (Tintaya, Quechua and Antapaccay), Katanga (Katanga, Monte Rojo and San José), Las Bambas Sulfobamba, Querobamba, and Chalcobamba), Cotabambas (Azulccaca, Ccalla, Huaccla, and Ccarayoc), and finally Morosahuas cluster (Llollacsá, Cha-Cha, Quenco, Chicaccasa) (Perelló et al. 2003). All the abovementioned deposits are located in the eastern part of the Andahuaylas-Yauri batholiths. However, the presence of many occurrences is also known in the western part, such as Angostura, Trapiche, Utupara, Santa Rosa de Virando, Lahuaní, Antilla, San Diego, Yuringa, Jara – Jara, Leonor, Los Chancas, Haquira, Cristo de los Andes, etc. The presence of many small gold vein occurrences associated with limestone must be stand out, which are currently being worked artisanally.

This belt is currently considered as an extension of the Chile Eocene-Oligocene Belt, where important porphyry-type deposits can be found. The initial strontium isotopic ratios indicate that the Andahuaylas-Yauri batholith porphyry are of moderate to low tonnage (Bustamante, 2008).

The contribution of this research is that it presents new geochemical, geochronological, isotopic, and petromineralogical interpretations, which will help to better understand the metallogeny of the area. It also presents updated information of different mineral occurrences that strengthen the economic geology of the area, thus being very useful for prospectors as an updated guide for explorations.

1. - GENERAL OUTLINES

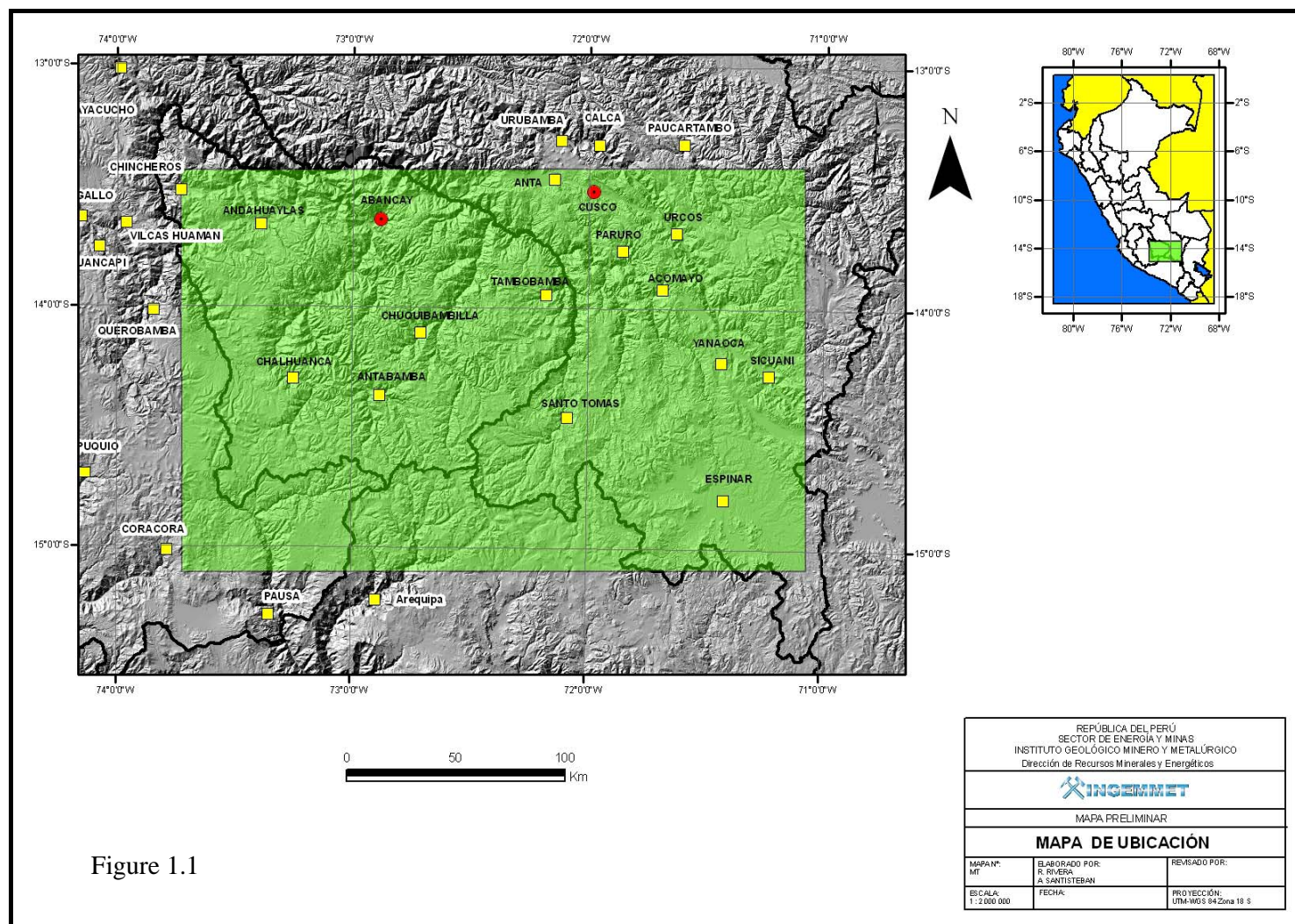
1.1 Study zone location

This study area is in the Western Cordillera of the Ayacucho, Apurimac, Cusco, and Arequipa regions. It includes 12 quadrangles (1:100,000 scale) approximately, comprising the provinces of Sucre and Anta in Ayacucho; Antabamba and Andahuaylas in Apurimac; Urubamba and Chumbivilcas in Cusco; Espinar and La Unión in Arequipa (Fig. 01). The study area is delimited by the following coordinates:

13° 00' 00" – 15° 00' 00" LS

74° 00' 00" – 71° 00' 00" LW

The Andahuaylas-Yauri belt covers an area of approximately 25 000 square km, and is located at a distance of approximately 300 km from the Peru-Chile trench. This area has one of the strongest Andean orogenic sialic crusts (50 to 70 km; James, 1971) and it is located in the transition zone between a normal subduction regime between southern Peru and northern Chile, and a flat subduction zone in the central and northern Peru (Cahill and Isacks, 1991). It is located immediately southeast of the Abancay deflection (Marocco, 1978). Metallogenetically, the Andahuaylas batholith is within the main arc domain (Clark et al., 1990), and within the XV belt, named Porphyry-skarn Cu-Mo (Au, Zn), and Au-Cu-Fe deposits, related to the Eocene-Oligocene intrusive (INGEMMET, 2009). The region includes the area of the intermountain depression between east and west of the Cordilleras, and the northernmost area of the Altiplano. The western part of the belt is characterized by a steep mountainous topography, where snow-capped mountain ranges are above the 4500 and are cut by 2000m-deep canyons. These canyons are the main drainage system in the región and include the Santo Tomas, Urubamba, Apurimac, Vilcanota, Mollebamba, and Antabamba rivers. All these drains are directed towards the Amazon basin. The eastern and southern part of the region is characterized by a gently topographic undulation of a platform (approx 4000 m) that extends into the Bolivia altiplano.



1.2 Accessibility

The main and fastest way to Access the study area is by air, departing from the "Jorge Chavez" International Airport (Lima), and landing in the "Velasco Astete" Airport (Cusco). The flight lasts approximately 1 hour and 15 minutes. Another route of the flight would be from Lima ("Jorge Chavez" Airport) to Juliaca ("Manco Capac" Airport). The flight lasts approximately 1 hour and 45 minutes, and from Juliaca to the city of Cusco it takes approximately 5 hours on a paved road.

From Cusco to the small towns within the region the access routes are generally gravel roads and sometimes unpaved roads.

Some of the main gravel roads are:

- Cusco – Abancay – Andahuaylas
- Lima – La Oroya – Huancayo – Ayacucho – Andahuaylas
- Nazca – Puquio – Andahuaylas.

1.3 Antecedent

Until the late 80's limited geological research had been conducted in the Andahuaylas-Yauri belt, and it was primarily known for its Cu magnetite skarn deposits (Terrones, 1958; Bellido et al., 1972; Sillitoe, 1990; Santa Cruz et al., 1979; Enauidi et al., 1981; Aizawa y Tomizawa, 1986),

These occurrences were considered by many researchers as copper skarn associated with sterile intrusions (e.g. Enauidi et al., 1981; Noble et al., 1984), although the potassic alteration in porphyry stocks hosts have been described and characterized as such (Yoshikawa et al., 1976; Noble et al., 1984). At the end of the 80's a complementary regional work of detailed geological studies in Tintaya and Katanga (Carlier et al., 1989), followed by an intensive grass-roots exploration in the region during the 90's, proved the alteration and mineralization styles, which are typical of the porphyry systems (e.g. Fierro et al., 1997), and resulted in the discovery of additional porphyry Cu with economic potential, such as Antapacay (Jones et al., 2000), Los Chancas (Corrales, 2001), and Cotabambas (Perelló et al., 2002), as well as porphyry-skarn mineralization in Corocohuayco (BHP Company Limited, 1999). Zinc-rich Mississippi Valley-type

mineralization was also found in the region (Carman et al., 2000) adding these to the metallogenetic diversity of the belt.

There are numerous geological reports and articles prepared by different mining companies operating within the study area, and among them we can mention those made in the Trapiche mineral deposit, Utupara, Cotabambas, etc. Among the regional studies we can mention that of Perello et al. (2003) "Porphyry-Style Alteration and Mineralization of the Middle Eocene to Early Oligocene Andahuaylas-Yauri Belt, Cuzco Region, Peru", as well as regional work conducted by INGEMMET which has been published, such as the bulletins of the National Geological Chart – Series A

1.4 Work Methodology

It must be emphasized that the work methodology was conducted based on a regional scale (scale of 1:300 000) including 100% of the Andahuaylas batholith outcrops. The development of the entire project encompasses three major stages.

The first phase known as the office work I, is characterized by an extensive compilation of technical and scientific information, which is synthesized and screened in geological folios using

version 9.3 of Arc GIS software. All this information makes it possible the assessment of the area from different points of view combining geochemical, structural, geochronological, and isotopic information. In addition, each of these folios has different geological value depending on the reliability of the information that has been projected onto them

The second stage is considered by some geologists as the most important one, and it has direct relation with the field stage. This stage was conducted in three field trips, 21 days each. During this period main deposits of the Andahuaylas batholith were visited. The purpose of the field trips was to check and take an inventory of the occurrences reported in previous works, and to take rock samples of the visited deposits, as well as to describe the main field characteristics that will allow us to compare or establish the differences between them.

The last stage is known as the office work stage II. During this stage the samples collected in the field are sent to the laboratory for their respective geochemical analysis

(Atomic absorption, XRF, ICP-MS, etc.). Polished and thin sections of the samples previously selected are also examined. Upon receiving the geochemical results, these are interpreted and the folios are updated with the new data. Cross-checking all the geological information, we try to find some new relations that allow us to have better exploration guidelines, as well as to try to understand the genesis of the different types of mineral deposits in our study area.

2.- GEOLOGIC SETTING

The geology of the region is dominated by a set of Cenozoic plutons named Andahuaylas – Yauri Batholith which intrude the Mesozoic marine sedimentary sequence that consists of clastic rocks of the Yura Group (Jurassic), carbonate horizons of Ferrobamba Formation (Cretaceous) and to a lesser extent dominantly lacustrine sedimentary rock of the Chilca and Quilque formations (Paleocene - Eocene). To the north the geology is mainly dominated by several volcanic sequences and volcanic - sedimentary (Anta Formation, middle Eocene – lower Oligocene) and continental sedimentary rocks including the "red beds" series of the San Jerónimo Group (Lower Eocene-lower Oligocene; Carlotto et al., 1999).

2.1 Regional Stratigraphy

In the study area, the oldest rocks are Precambrian gneisses that found northwest of Cusco, then exist a Paleozoic sequence (Cambrian-Lower Permian) of more than 10 000 m thick constituted by volcanosedimentary, marine and continental sequences (Marocco, 1978; Carlotto et al., 1996a; Carlotto et al., 1997). At the top of the pre-Andean basement lie volcanic and clastic rocks sequences of the Mitu Group (Permian-lower Triassic), with over 1000 m in thickness. During the Mesozoic and Cenozoic the sedimentation is mostly Jurassic and Cretaceous and was developed in two main basins, the West Basin or also named the Arequipa Basin (Vicente et al., 1982) and the Eastern Basin or also named the Putina Basin (Jaillard, 1994), these basins were separated by a structural high called Cusco-Puno which includes about 900 m of red beds interbedded with shale, limestone and gypsum (Carlotto et al., 1993; Jaillard et al., 1994). Arequipa Basin becomes the Western Cordillera, and consists of a sedimentary sequence of about 4 500 m thick.

Putina Basin is a Upper Cretaceous sedimentary sequence that consists of marine clastic and carbonate rocks, with a thickness of about 2 600m (Jaillard et al., 1993, Jaillard, 1994, Cardenas et al., 1997).

From Eocene to Lower Oligocene in the study area basically there are two stratigraphic units: The San Jerónimo Group and Anta Formation.

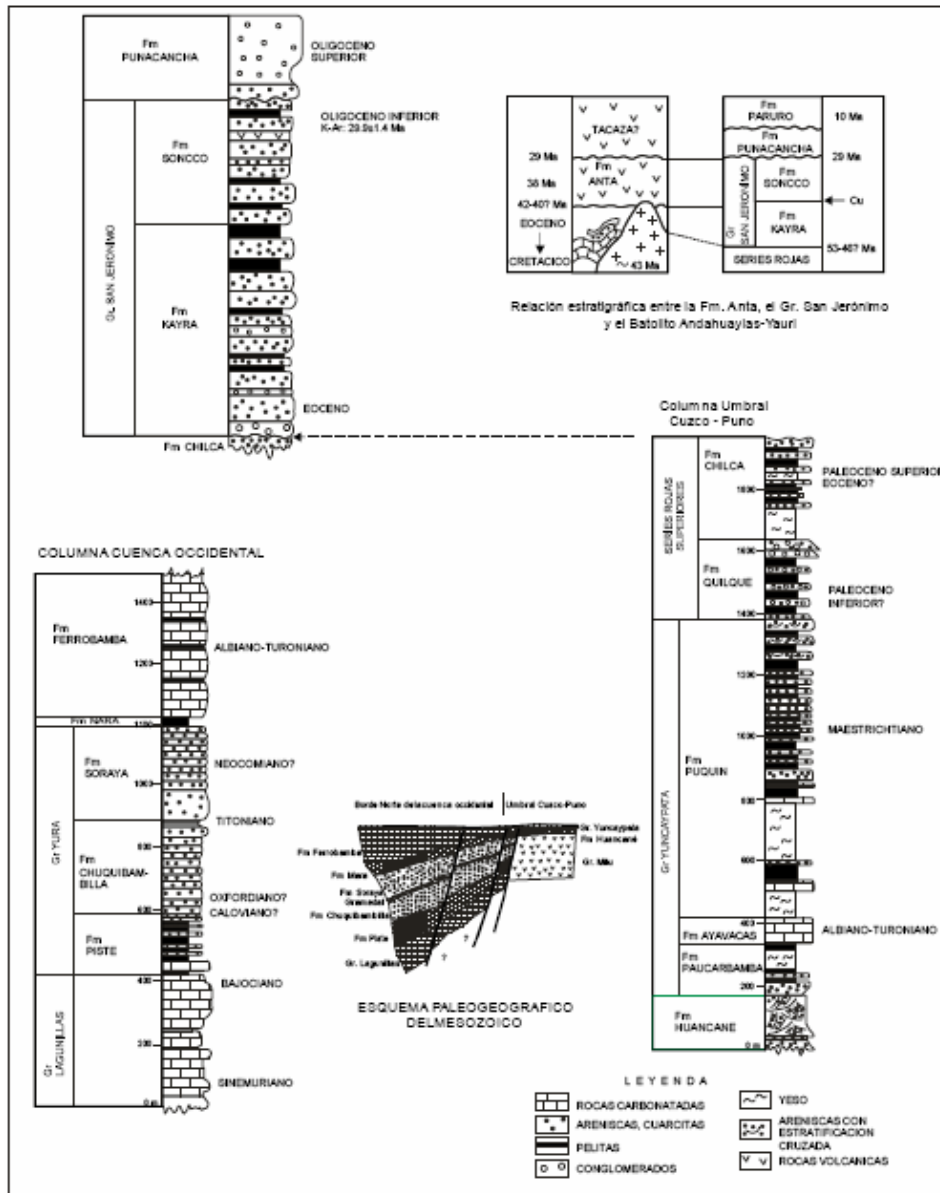


Fig. 2.1.- Regional stratigraphic columns (Carlotto et al., 1996a, 1999).

San Jerónimo Group is constituted by Kayra and Soncco formations, consisting of a red beds sequence of 4 500m thick composed of sandstone, shale and volcanic microconglomerates, the San Jerónimo Group has been dated in the upper tuffs horizons of the Soncco Formation by K-Ar giving age of 29.9 ± 1.4 Ma and by Ar-Ar with 30.84 ± 0.83 Ma (Carlotto, 1998, Fornari et al., 2002). Between Cusco and Sicuani in the Soncco formation basal sandstone there are mineralized horizons of Cu stratiform with chalcocite hypogene, bornite and supergene copper oxides (Cardenas et al., 1999) and show some similarities to the Red Beds deposits of the Bolivian Altiplano and northern Chile (Travisany, 1979). The San Jerónimo Group is the equivalent of the Puno Group in the

peruvian Altiplano. Anta Formation is a volcanic sequence of about 1 000 m in thickness, this sequence has been dated to the southwest of Cuzco in two biotite-rich dacitic flows, the first from the middle of the formation by the method of K-Ar giving ages of 38.4 ± 1.5 and 37.9 ± 1.4 Ma, and the second from basaltic horizon at the top of the unit dated by K-Ar method giving an age of 29.9 ± 1.1 Ma.

During the upper Oligocene to Miocene was developed a siliciclastic sedimentation represented by the Punacancha formation with 1500 - 5000 m thick, and the Paruro formation with more than 1100 m thick. (Perello et al., 2003), in the region also there are volcanic rocks generally calc-alkaline composition in the sequences of the Cordillera Occidental (Inner - Cordillera Occidental of Sandeman et al., 1995) and the Altiplano, which includes the Sillapaca and Tacaza Groups. The Tacaza Group is dominated by trachyandesites, andesite and rhyolite tuff (Klinck et al., 1986; Wasteneys, 1990) with shoshonitic rocks in the Santa Lucia area, to southeast of Yauri, and were dated around 32 and 24 Ma (Clark et al., 1990; Sanderman et al., 1995).

2.2 Intrusive Rocks

The magmatism is represented by multiple intrusive bodies that regionally belong to Andahuaylas - Yauri Batholith. These rocks outcrop in a belt of NW-SE direction parallel to the andean region direction between the towns of Andahuaylas in the northwest and Yauri in the southeast, with an approximate length of 300 kilometers and a width varying between 10 and 60 kilometers (Bonhome and Carlier, 1990). The westernmost outcrops constitute the bulk of the batholith (bodies up to 70 km in diameter), while southeast this unit appears as a string of minor bodies, about 10 km in diameter.

The batholith is composed of several intrusive units that tend to focus on two major groups: a group of diorite and quartzdiorite which constitutes 80% of the batholith and a smaller group composed of granodiorite, diorite and dacite minor stocks and microdiorite dikes. Field work generally indicate that the facies of the first group are older, which has been confirmed by geochronological dating (Carlotto, 1998).

Middle Eocene – Lower Oligocene plutonism (~ 48–30 Ma)

Intrusive rocks this year old are referred to Andahuaylas-Yauri Batholith (Carlier et al., 1989; Bonhohomme and Carlier, 1990), The outcrops of the batholith have a northwestern direction and are located at the northeastern edge of the Cordillera

Occidental. The emplacement of the batholith occurred in two main stages (Perello et al., 2003).

In the early stage occurred intrusions of gabbro, olivine gabbro, gabbro-diorite and diorite (Carlier et al. 1989, 1996), exposed mainly along the northern edge of the batholith between Curahuasi and Limatambo (Carlier et al., 1989; Ligarda et al., 1993). Through petrographic studies were determined that these rocks are typical calc-alkaline facies that crystallize in the base of the shallow magma chambers, with emplacement temperatures around 1000° C and pressures between 2 and 3 Kbar.

During the intermediate stage were emplaced rocks with intermediate composition such as monzodiorites, quartzdiorite, granodiorite and quartz monzodiorites (Carlier et al., 1989; Bonhomme and Carlier 1990; Carlotto, 1998) which are distributed throughout the region constituting the main part of the batholith.

Upper Oligocene plutonism (~ 29–26 Ma)

The intrusive activity correspond a series of small syenites stocks with an age of about 28 Ma in the area of Curahuasi (Carlotto, 1998). These intrusions are part of a large magmatic province that also includes basanites, trachytes, phonotefrites in the Ayaviri region, with dated ages between 29 - 26 Ma (Carlier et al., 1996, 2000).

3.- ECONOMIC GEOLOGY

INTRODUCTION

This report contains geological information obtained in the field conducted to study the prospective areas and inactive mines belonging to Andahuaylas-Yauri Batholith. The work was performed under the agreement between KIGAM and INGEMMET to study the economic potential of Batholith Andahuaylas – Yauri (Fig. 3.1)

Inactives mines visited were: Angostura, Santa Rosa de Virundo, Yuringa, Atacancha, Yuringa, San Diego, Lahuani and Jara Jara. It also visited the Utupara exploration prospect and the surrounding Las Bambas.

The mineralization and alteration in most inactive mines are mainly related to structures (veins) with economic content of gold, silver and copper. Most of these structures are associated with the presence of iron and manganese oxides (Santa Rosa, Angostura, and Atacancha Yuringa). In San Diego the style of mineralization is characterized by polymetallic veins that contain bornite, chalcopyrite and molybdenite. Lahuani area near San Diego is characterized by alterations, veins quartz and disseminated mineralization of porphyry Cu. Utupara is a porphyry complex that includes mineralization porphyritic filoneano type, skarn and porphyritic.

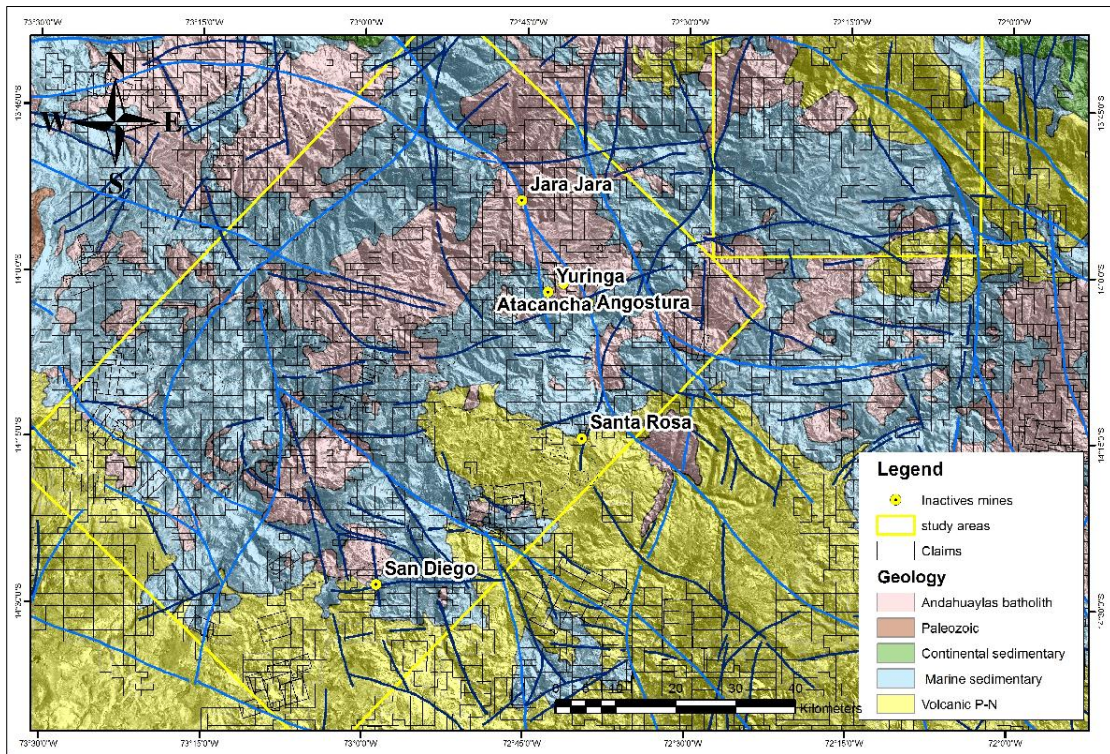


Figure 3.1: Location Map of inactive mines visited

VISETED AREAS

3.1.- Angostura

Location: The area is located in the district of Curpahuasi, province of Apurimac, department of Grau to 4.7 km northwest of Vilcabamba city. Has the following central coordinates 753924E, 8445927N and 3527 meters of altitude. (Fig. 3.2)

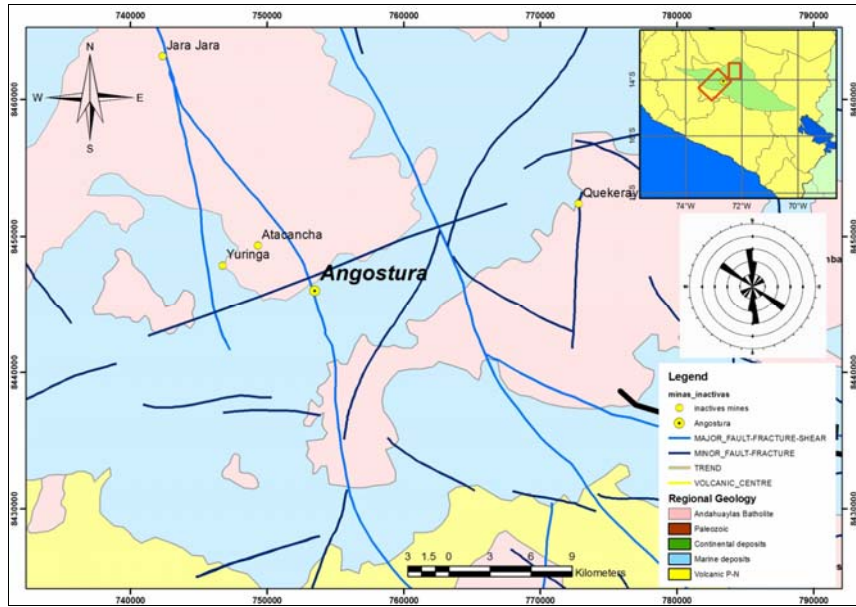


Figure 3.2: Angostura location Map

Geology

Lithology

In the outcrop area the following types of rocks:

- **Diorite:** that is characterized by light gray, medium-grained texture phaneritic, plagioclase phenocrysts <3mm in 70%, 10% hornblende, quartz subordinate <3%.
- **Limestone:** Displays color gray, fine-textured, incipient recrystallization, calcite veins millimeter. The strata are largely folded.
- **Marble:** white to light gray color with characteristic recrystallization of calcite, coarse texture. Is restricted to the contacts of limestone with iron oxide structures.

Structural

The area is dominated by three structural systems whose orientations are N80E/80NW, N35E/55SE and N30E/85NW. The structures of iron oxides and breccias related to the mineralization appear to follow the course N70-80E/80NW.

Alterations

The alterations identified in this area are not very extensive and are restricted to the contact between the dioritic intrusive and limestone producing a marmolization. Also brecciated structures with iron oxides produce a weak silicification.

- **Marbled zone:** Produced by the recrystallization of the limestones from metasomatism generated by contact between the intrusive diorite and limestone. The marble is characterized by its whitish, coarse-textured and is associated with calc silicate minerals such as wollastonite.
- **Silicification:** is weak and is related to the brecciated structures with iron oxides. You can identify a silica veining in the contact area.
- **Propylitization:** Weak to moderate affecting the diorite intrusive. It is characterized by the presence of chlorite and epidote which are replacing mafic minerals such as hornblende.

Mineralization

The main mineralization is associated with brecciated structures (shear zones) in the limestone whose orientation is N70-80E. These structures are associated with the presence of iron oxides, manganese oxides and so subject to silica, pyrite and chalcopryrite. The principal metal extracted is gold and this is associated with Fe and Mn oxides such as limonite, hematite, magnetite and pyrolusite.

Discussion:

The mineralized structures correspond to tectonic breccias are affecting marbled limestone and in turn are in contact with the intrusives. It is possible that the mineralization was deposited along the axis of an anticlinal flank very closed. The economic potential of the area is defined for gold mineralization which is hosted in these structures.



Photo 3.1: Marbled limestone outcrop cut by structures of iron oxides. Note the mining work on the road
Photo 3.2: Diorite outcrop cut by felsic veinlets



Photo 3.3: Structure of hematite-goethite-limonite, pyrolusite of marbled limestone cutting direction N70W. Note the mining work.
Photo 3.4: Area of contact between intrusive diorite and limestone marbled.

3.2 SANTA ROSA DE VIRUNDO

Location

The Virundo Santa Rosa mine is located in the district of Turpay, Grau province and Apurimac department, to 19 km southwest of the Vilcabamba city. The central coordinates are 751783E 8423436N and 4018 meters of altitude. (Fig. 3.3)

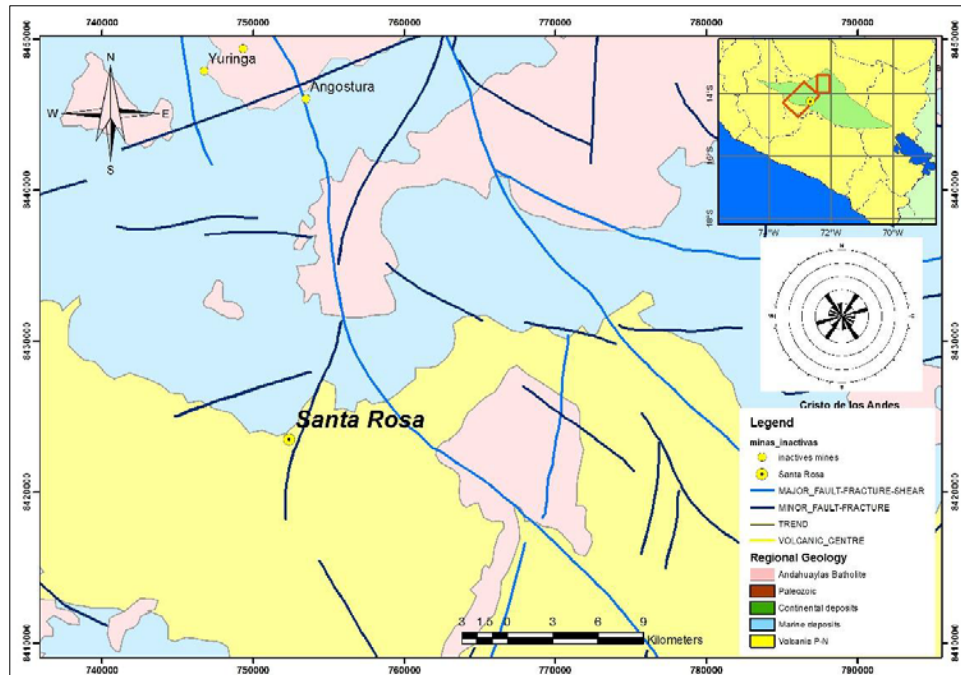


Figure 3.3: Santa Rosa location Map

Geology

Lithology

The area is dominated by limestone, to a lesser extent are intrusive and pyroclastic rocks.

- **Limestone:** They are gray to dark gray color, fine texture micrite, with millimetric veinlets of calcite. In some areas these limestones are brecciated by faulting.
- **Dacite porphyry:** light gray-colored stock with crystals of plagioclase and potassium feldspar <5mm. Fine matrix of plagioclase with hornblende <3mm subordinate quartz and <3%. The rock is moderately propilitizada and weathered.
- **Lapilli tuff:** white color, polymictic fragments, matrix rhyodacitic. The rock is mostly obliterated by the texture change.

- **Marble:** white to light gray coloration, recrystallization of calcite, coarse texture. Is restricted to the contacts of limestone with iron oxide structures.

Structural

The area is dominated by three structural systems whose orientations are N70E/55NW, N20E/70SE, N60W/85NE. The structures of iron oxides and breccias related to mineralization are the direction N70-80E.

Alterations

- **Silicification:** is weak and is affected mainly the lapillítica tuff. In some areas is associated with kaolin
- **Argilization:** Subsequent to the Toba lapillítica, kaolin minerals is replacing the matrix and obliterating the original rock texture.
- **Marbled zone:** produced by recrystallization of the limestones from metasomatism generated by contact with dacite porphyry. The marble is characterized as gray-colored gray-white, coarse to medium and associated with calc silicate minerals such as wollastonite.

Mineralization

The mineralization is associated with structures of N70-80E due to iron oxides (hematite, goethite, limonite) manganese oxides (pyrolusite), jarosite, pyrite, chalcopyrite and galena subordinate. It is also common fractures found in copper oxides malachite and azurite.

Discussion

The mineralized structures consist of brecciated shear zones affecting the limestone. The mineralization is predominantly gold in sulfides (pyrite) that have been oxidized and leached. It is common to identify iron and manganese oxides rich in gold and silver. In a smaller proportion are copper oxides (malachite and azurite). The potential of the area is defined for structures (breccias) with gold and silver



Photo 3.5: brecciated structure with oxides of manganese and iron oxides, hematite-goethite, limonite, pyrolusite and marbled limestone cutting direction N70W. Note the mining work.

Photo 3.6: Structure subvertical with manganese oxides and iron oxides in limestone marbled.



Photo 3.7: brecciated structure with oxides of manganese and iron oxides hematite-goethite-limonite. Direction N70W. Esperanza pit.

Photo 3.8: Units dendritic pyrolusite coating fractures in marble.

3.3 ATACANCHA

Location

It is located in the district of Curpahuasi, Grau province, Apurimac department, 10 km NW of the Vilcabamba city . The central coordinates are 748887E, 8447800N and 4318 meters of altitude. (Fig. 3.4)

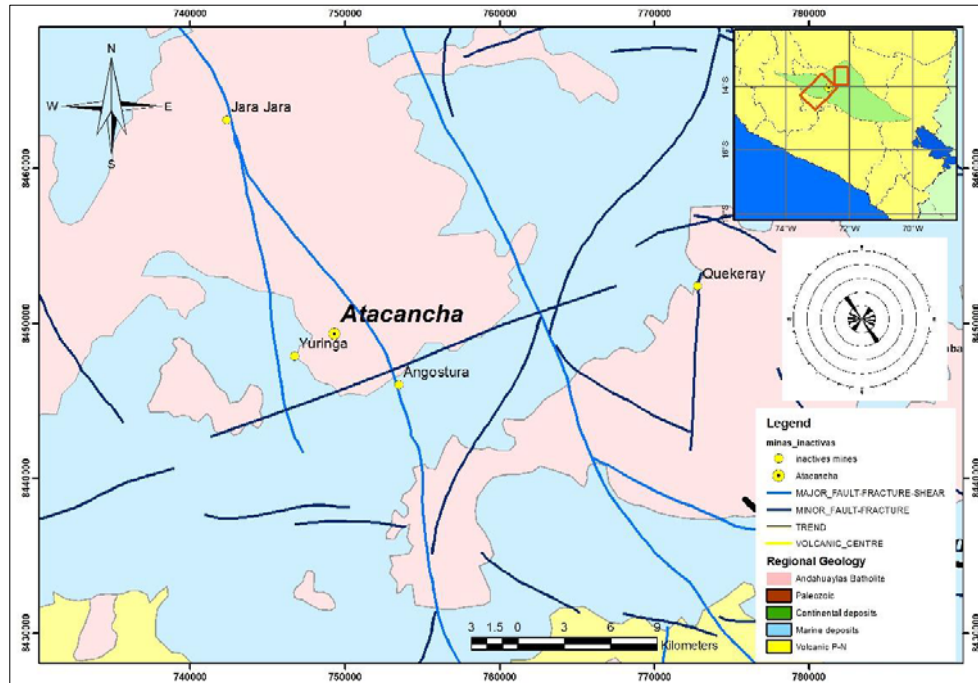


Figure 3.4: Atacancha location Map

Geology

Lithology

In the outcrop area limestone, diorite and marble.

- **Limestone:** outcrops of gray to dark gray color, fine texture, micritic, with millimetric veinlets of calcite. In areas is partly brecciated by faulting. It is common to have sigmoid veins and fractures filled by calcite.
- **Diorite:** This intrusive is characterized by a light gray color, the texture is medium grain phaneritic predominantly plagioclase <5mm, hornblende <3mm.
- **Marble:** It is characterized by gray to white colors in some cases you can identify layering, coarse texture is characterized by recrystallization of calcite.

Structural

The area is dominated by three main structural systems whose orientations are N55W/55SW, N20E/83NW, N50W/80NW. The structures of iron oxides and breccias related to mineralization N55W/55SW remain on course. Failures have been identified course of conduct which have a dextral direction N20-25E.

Alterations

- **Marbled zone:** Produced by recrystallization of the limestones from metasomatism generated by contact with the diorite intrusive. The marble is characterized as gray-colored gray-white, thick texture is medium and is associated with calc silicate minerals.
- **Silicification:** Your presence is limited to structures, is weak and appears to affect the contact areas with limestone and diorite.
- **Calc-silicates:** It occurs due to contact between the limestone structures. Is prograde with minerals such as pyroxene and calcite.

Mineralization

The mineralization is associated with N55W/55SW course structures with iron oxides (hematite, goethite, limonite) and sulfides related to the presence of Au and Ag have a weak silicification related to the presence of calc silicate minerals such as pyroxene and partners the presence of sulphides such as pyrite and chalcopryrite in cubic crystals

Discussion:

The mineralization is mainly related to the presence of structures of N50-60W characterized by the presence of iron oxides and a subordinate sulfides (pyrite, chalcopryrite), suggesting that these structures were initially composed of sulfides and quartz and a lesser proportion which were subsequently been oxidized and leached in many cases leaving boxwork type textures with iron oxides. The potential in this area is defined for veins with Au and Ag



Photo 3.9: brecciated structure with iron oxides hematite-goethite-limonite N55W course cutting limestone.

Photo 3.10: Area of contact between diorite with limestone in the presence of pyroxene-calcite and pyrite.



Photo 3.11: Structure with iron oxides hematite-goethite-limonite N55W course cutting limestone. Informal mining work.

Photo 3.12: Area of contact between diorite and limestone with pyrite and chalcopryite with pyroxene-calcite

4.-YURINGA

4.1. Location:

The area is located in the district of Curpahuasi, province of Apurimac, Grau department to 11 km NW of the city of Vilcabamba. Its central coordinates 747264E, 8448029N and an altitude of 4434 meters. (Fig. 3.5)

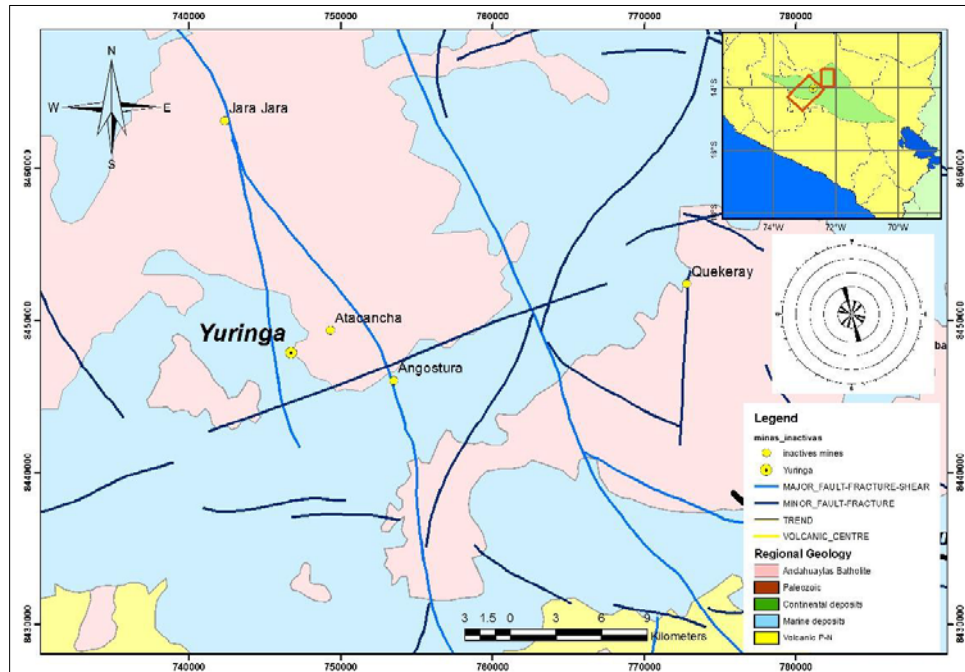


Figure 3.5: Yuringa location Map

Geology

Lithology

Limestone outcrop in the area, diorites, tonalites and marble.

Limestone, outcrops of gray to dark gray color, fine texture, micrite with veins of calcite.

In zone is brecciated by faulting. It is common to have sigmoid veins and fractures filled by calcite.

- **Diorite:** This pluton is characterized by a light gray color, the texture is medium grain phaneritic predominantly plagioclase <5mm, hornblende <3mm.
- **Tonalite:** light gray, medium-grained texture phaneritic. They are as essential minerals to plagioclase (50%) and quartz (15%) with grain sizes smaller than 5mm. It has also been identified subordinate hornblende and feldspar.
- **Marble:** It is characterized by gray to white colors in some cases can be seen banded texture, thick texture is characterized by recrystallization of calcite.

Structural

There are three main system whose directions are: N70E/40NW, N10E/65SE, N25E/58SE faulting has been identified direction of N25E oriented dextral and normal faulting oriented N10E and N75E. The veins follow the following guidance N70E/40NW.

Alterations

- **Marbled zone:** Produced by the contact between limestone and intrusive diorite and tonalite. The marble is characterized as gray-colored gray-white, coarse to medium.
- **Silicification:** Is restricted to the veins, is of moderate intensity appears to affect the host rocks.

Mineralization

The mineralization is related to veins with silver sulfosalts assemblages associated with pyrite - barite-siderite. Structures are often brecciated and related fault zones oriented normal type N70E/40NW. These structures are partially oxidized generating presence of iron oxides such as goethite, limonite, jarosite. Can also be identified as chrysocolla copper oxides.

Discussion

The veins are related to normal faults N70E orientation is characteristic of these the presence of silver sulfosalts (pyrargyrite) mineral typical low-temperature hydrothermal environments and related to the presence of barite (high) which would indicate that these veins would be the tops of the highest levels of the system. The presence of gold is subject so does the copper oxides.



Photo 3.13: Yuringa mine of intrusive rocks (tonalite). Note the fracture rate associated with normal faults. Informal mining work.

Photo 3.14: Structure sigmoid in dextral fault zone associated with vein with barite and calcite.



Photo 3.15: dextral fault plane. Note the kinematic structures indicating the direction of motion. Inside the mine.

Photo 3.16: Display of hand vein. Silver sulfosalts crystals intergrown with barite and associated with iron oxides.

5.- SAN DIEGO

Location

The area is located in the district of Juan Espinoza Medrano, province of Apurimac department Antabamba 8 km SW of the city of Mollebamba. Its central coordinates 717370E, 8399270N and an altitude of 4606 meters. (Fig. 3.6)

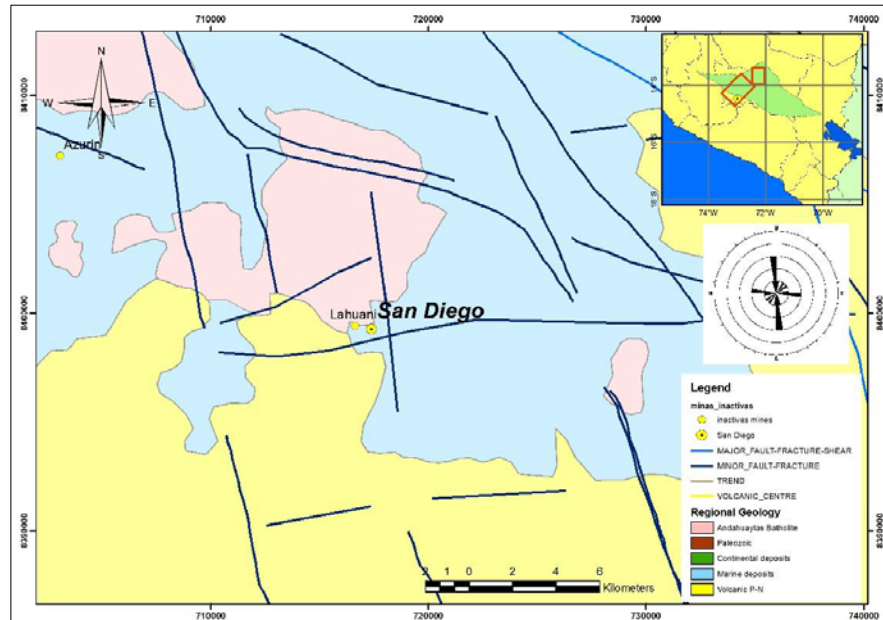


Figure 3.6: San Diego location Map

Geology

Lithology

- **Limestone:** dark gray-colored outcrops, fine texture micrite with veins of calcite. In zone is brecciated by faulting.
- **Monzogranite:** Intrusive characterized by a gray with pink hue. The texture is medium grain phaneritic. Minerals predominate as plagioclase (<2 mm), feldspar (<3mm) and quartz to a lesser extent. Hornblende, biotite and magnetite as accessory minerals.
- **Diorite:** This intrusive is characterized by a light gray color, the texture is medium grain phaneritic, essential minerals are plagioclase <3mm and subordinate feldspar. The main accessory mineral is hornblende.
- **Marble:** It has gray to dark gray color, is caused by the metasomatism occurred between the intrusive diorite and monzogranite with limestone. The degree of recrystallization is moderate

Structural

We have identified three main systems whose directions are 70E/70SE, NS/60E, N60W/45SW. The veins are controlled by the system N70-80E 60-70 tilt to the SE. Has been identified dextral faulting with NS and normal faulting N80E direction. Also faulting also occurs due to N25E oriented dextral and normal faulting oriented N10E and N75E. The veins follow the guidance N70E/40NW.

Alterations

- **Silicification:** is related to the presence of veins which moderately altered host rock to produce a replacement of silica minerals in the intrusive diorite. This silicification is local and is restricted to halos of the grain.
- **Calc-silicates:** There are two types of alteration type calc-silicates with prograde and retrograde assemblages. These changes are related to the contact between the intrusive diorite with limestone also to the presence of the grain.
- **Prograde:** Characterized by the assemblage garnet-pyroxene
Retrograde: Mainly actinolite-chlorite, amphiboles are replacing pyroxenes.

Mineralization

The mineralization is controlled by grain direction N70E dipping 70SE, filling textures are being able to identify the following assemblages:

1st event: quartz-molybdenite + chalcopryite + pyrite

2nd event: hematite (specular)

3rd event: chalcopryite-pyrite-bornite-calcite

4th event: calcite - quartz crystals, hyaline

Discussion

The presence of at least four mineralization events indicates the existence of multiple phases in the grain filling the most important from the economic point of view as the third event that brings significant copper mineralization (chalcopryite-pyrite-bornite- calcite). It is also important to mention that these structures generate a halo in their respective host rock with altered calc-silicates (pyroxene, garnet and actinolite) without mineralization identified to date.



Photo 3.17: Pit in old work of mine showing fault plane with chalcopryrite, molybdenite and copper oxides.

Photo 3.18: Old mine.

6.- LAHUANI

Location:

The area is located in the district of Juan Espinoza Medrano, province of Apurimac department Antabamba 8 km SW of the city of Mollebamba. Its central coordinates 716628E, 8399384N and an altitude of 4610 meters. (Fig. 3.7)

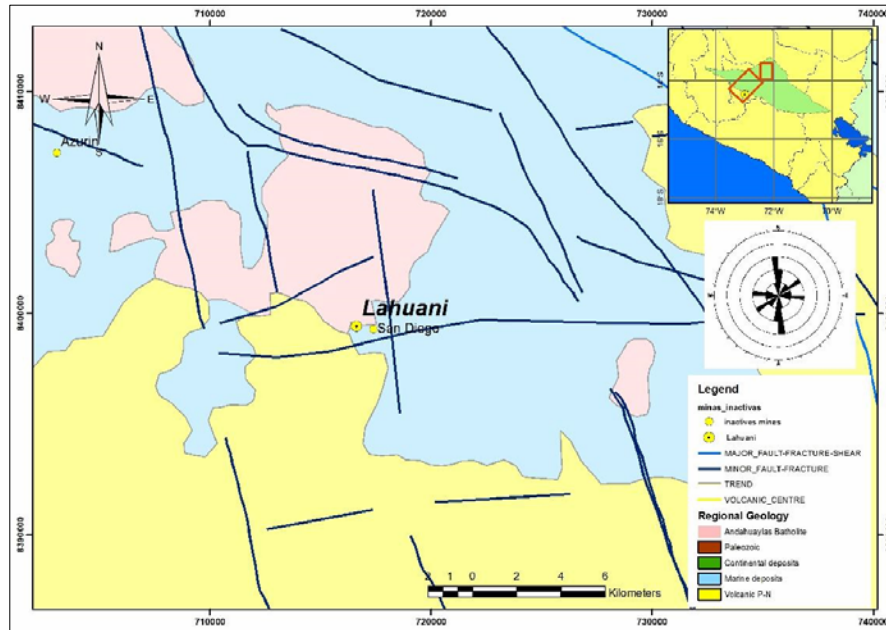


Figure 3.7: Lahuani location Map

Geology

Lithology

- **Limestone:** characterized by presenting a dark gray color, fine texture with veins of calcite micrite. It is common to have sigmoid veins and fractures filled by calcite.
- **Monzogranite:** characterized by intrusive gray with pink hue. The texture is medium grain phaneritic. Minerals predominate as plagioclase (<2 mm), feldspar (<3mm) and quartz to a lesser extent. Also hornblende, biotite and magnetite as accessory minerals.
- **Granodiorite:** This intrusive is characterized by having a light gray color, the texture is medium grain phaneritic, essential minerals are plagioclase <3mm feldspar <3mm. and quartz. The main accessory mineral is hornblende.

Structural

The area is dominated by three main systems whose directions are N70E/70SE, NS/60E and N50W/45SW. These systems have been recognized in the field but can also be identified at the regional level from the interpretation of satellite images. N70E system is associated with failure of standard and related to polymetallic veins with chalcopyrite-bornite-molybdenite-pyrite, as in the San Diego mine. N40-50W system is related to calcite-galena veins with iron-oxides. NS systems are dominated by fault type associated with veinlet sinextral and quartz in the monzogranite and granodiorite.

Alterations

- **Quartz-sericite-pyrite:** We present affecting the monzogranite and granodiorite. Is sericite replacing plagioclase crystals and feldspar in some cases to obliterate the texture of the rock. The rock matrix has been altered by an intergrowth of sericite with quartz in the presence of disseminated pyrite.
- **Silicification:** is related to the presence of veins which moderately altered host rock to produce a replacement of silica in the intrusives. This silicification is local and is restricted to halos of the grain.
- **Calc-silicates:** These changes are related to contact with the intrusive veins and limestone. It has identified the following types:

Prograde: Characterized by the assemblage garnet-pyroxene

Retrograde: Mainly actinolite-chlorite, amphiboles are replacing pyroxenes.

Mineralization

- **Vein type:** This first style is related to a structure with calcite-pyrite-galena, these veins causing the host rock altered calc silicate minerals.
- **Porphyry type:** It has been recognized in the area Lahuani Area. The mineralization is characterized by the presence of chalcopyrite disseminated in the intrusive rocks (granodiorites and monzogranite) which are affected by phyllic alteration (quartz-sericite-pyrite). Likewise, these intrusive rocks are cut by a series of quartz veinlets stockwork type arrangement. The quartz veinlets have a potassium feldspar halos and / or albite. In some cases, these veinlets are associated with pyrite and chalcopyrite. Magnetite-chalcopyrite veinlets and quartz-chlorite-pyrite have been identified by cutting the granodiorite in the central part of the area.

6.3. Discussion

The lithology, alteration and mineralization identified in the area of Lahuani suggests that area is highly prospective for porphyry deposits of Cu and polymetallic veins. Structurally occur intersection of three structural systems associated with the failure Mollebamba Regional. These systems are the same that control Trapiche porphyry deposits and Panchita near the study area. To continue with the prospecting work which should include a detailed mapping of the area so that you can characterize the lithology, alteration and mineralization in the area. Also also recommends the collection of rock samples to define more precisely the geochemistry of the area.



Photo 3.19: Outcrop of granodiorite with phyllic alteration (CZ-ser-py) and type veinlet quartz stockwork.

Photo 3.20: Granodiorite with stringers of magnetite-pyrite-chalcopyrite.

7.- Jara - Jara

Location

The area is located in the district of Lambrama, province of Apurimac, Abancay department to 1.0 km north of town of the same name. The central coordinates are 742900E, 8462500N and an altitude of 3770 meters. (Fig. 3.8)

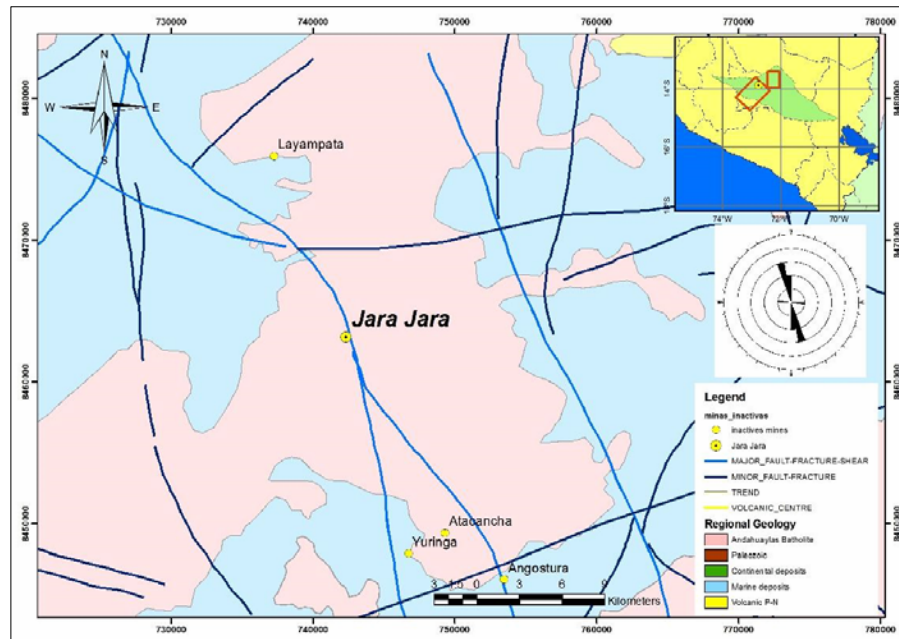


Figura 3.8: Jara Jara Location Map

Geology

Lithology

- **Limestone:** dark gray-colored outcroppings, fine texture micrite with veins of calcite. It is common for these fractures sigmoid veins filled by calcite.
- **Diorite:** This pluton is light gray in color, texture is medium grain phaneritic, essential minerals are plagioclase <3mm and subordinate feldspar. The main accessory mineral is hornblende.

Structural

We have identified three main structural systems whose directions are N75E/65SE, NS/65E, N80E/65SE. The veins are controlled by the system N70-80E 60-70 tilt to the SE. Has been identified dextral faulting with NS and normal faulting N80E direction.

El área se encuentra localizada en el distrito de Lambrama, provincia de Abancay departamento de Apurímac a 1.0 km al norte de la localidad del mismo nombre. Tiene como coordenadas centrales 742900E, 8462500N y una altitud de 3770 msnm.

Alterations

- **Silicification:** It is moderate and is restricted to the host rocks of the veins
- **Sericitization:** Relates to areas of faulting and the boxes of the grain. Affects the diorite and can identify a replacement of plagioclase by sericite. In some cases this alteration comes to obliterate the original rock texture.
- **Propylitization:** It is the most abundant and is affecting the diorite. Chlorite is the major mineral and this is replacing ferromagnesian has also been identified magnetite and pyrite.

Mineralization

The main style gold vein type mineralization. The veins of gold have economic content and are characterized by the presence of quartz with subordinate pyrite and chalcopyrite. The power of the structures is less than 30 cm and these are altered host rocks locally producing a moderate sericitization and in some cases a weak silicification. The vein system is controlled by faults oriented N70-80E affecting mainly dioritic rocks.

Discussion

The mineralization is related to structures that cut quartz granodiorite phaneritic texture. There are many ancient works some of which apparently date back to colonial times. The potential for this area of quartz veins with gold content



Figure 3.21: sample of quartz vein associated with pyrite, subordinate chalcopyrite and iron oxides

8.- UTUPARA

location

The area is located in the district of Huaquirca, province of Apurimac department Antabamba 4.5 km east of the city of Antabamba. Its central coordinates 734029E, 8410265N and is at an altitude of 4300 meters. (Fig. 3.9)

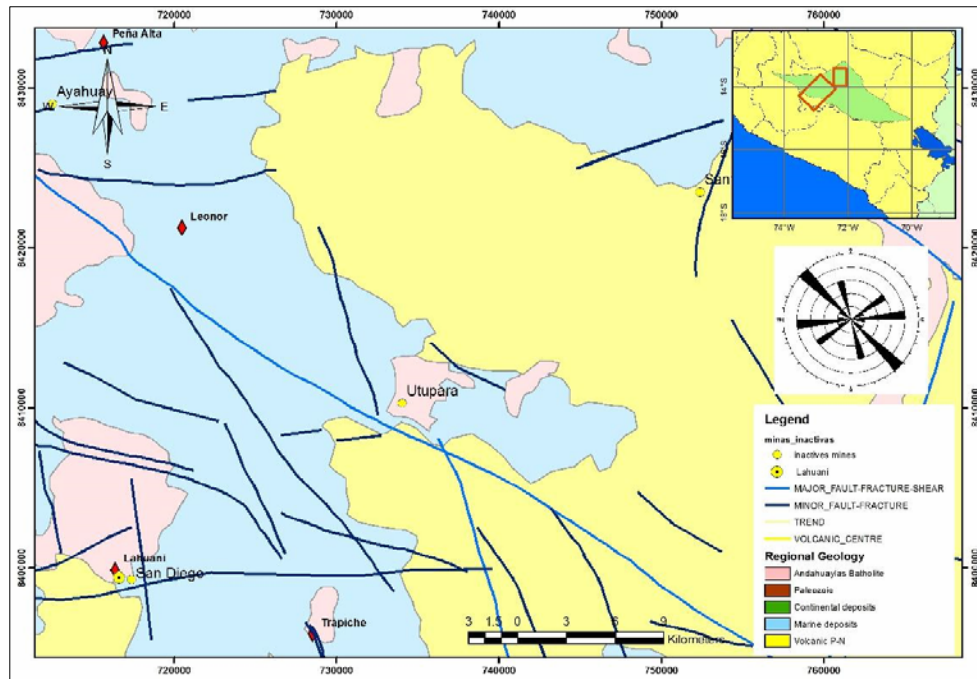


Figura 3.9: Utupara Location Map

Geology

Lithology

- **Biotite lamprophyres:** Rock leucocratic colored dark gray to black, consisting of 85% biotite megacrysts up to 8 cm. The crystals are well developed to be easily peelable, the matrix is sparse and consists of magnetite 10% and 5% feldspar. Veinlets is cut by centimeter to decimeter of potassium feldspar.
- **Diorite:** Rock melanocratic, gray to dark gray, medium grain holocrystalline, phaneritic equigranular texture. It is composed of plagioclase crystals subhedrales size <4 mm and up to 55%, clinopyroxene subhedrales <3 mm 25% amphibole (hornblende) <4 mm and 15%, biotite 3%, 1% magnetite. It is the largest rock outcrop in the area.
- **Porphyritic diorite:** Rock melanocratic, dark gray color that is characterized by well developed prismatic crystals of amphibole (hornblende) <2 cm. up to 25%,

also biotite crystals with sizes up to 1 cm., the matrix is composed of plagioclase by 60% which is in subhedral crystals <2 mm. Other minerals identified in the matrix are 5% magnetite, hornblende and biotite. This is probably the oldest intrusive rock in this area following the field observations which is cut by almost all other rock types.

- **Monzonite:** leucocratic, colored pink to gray to pink hue, holocrystalline medium grain texture is equigranular, composed mainly of elongated crystals of orthoclase <3 mm up to 35%, 45% subhedral plagioclase, mafic minerals are to a lesser extent and represented by amphibole (hornblende) euhedral crystals of size <3mm in 10%, biotite 5%, other 5%.
- **Biotite monzonite porphyry dyke:** It has a light gray color with greenish hue, is characterized by euhedral crystals of orthoclase present <6 cm. and 20% biotite crystals centimeter of 3 to 5 cm. by 10%. The matrix is characterized by being composed mainly of plagioclase equigranular subhedral <4 mm., Hornblende in large crystals <1 cm. magnetite and, less 1%. The biotite crystals are replaced by epidote by way of nests.
- **Andesite dike:** Is colored gray to dark gray, aphanitic to microporphyritic texture, euhedral plagioclase crystals of size <3 mm. and up to 30%. The matrix consists of fine-grained plagioclase up to 60%. The mafic elongated crystals are composed of amphibole (hornblende) <4 mm. up to 5%, biotite subordinate <1%, 2% magnetite.
- **Felsic dikes:** pinkness leucocratic rock composed mainly of feldspar (orthoclase) holocrystalline coarse. You can identify centimeter of orthoclase megacrysts. Cutting is so polydirectional diorite.
- **Porphyritic monzonite dike:** leucocratic, gray with pink hue, inequigranular, porphyritic texture, is composed of euhedral crystals of orthoclase <5mm subhedral plagioclase crystals forming mainly the rock matrix <2 mm and elongated idiomorphic hornblende crystals <3 mm., 3% biotite, magnetite <1%.

- **Quartzites:** Characterized by having more than 95% quartz in its composition, the quartz grains are recrystallized product of metamorphism. Outcrop mainly in the hill in banks of course Utupara N 45-70 W and 30-35 are dipping to NE.
- **Marble:** It has light gray, pink, white reaching depending on the degree of metamorphism. It consists in 95% recrystallized calcite. In many cases you can identify calcite veinlets subparallel to bedding. They arise mainly east of the study area and are limestone grading up to as they move away from contact with the diorite intrusive Utupara.
- **Breccias**
- **Intrusive breccias**
Are characterized by heterometric and polymictic, the pieces may be subrounded to subangular. When the breccia is clast-supported fragments are subangular decimetre size and mainly diorite and monzonite, when the breccia is matrix supported subrounded lithic fragments are the matrix in this case is mainly composed of plagioclase and biotite which have been altered to sericite, epidote, chlorite, iron oxides and clays, also identified disseminated pyrite. The main outcrop is concentrated in the area where evidence puppy at least two major events of brecciation.
- **Tectonic Breccia**
These breccias have been identified near the area of contact between quartzite and diorite, are characterized by angular to subangular fragments, monomitic heterometric and quartzite, these fragments reach centimeter sizes and are supported by a matrix of iron oxides and manganese.

Structural

Regionally, the study area is located on the southern edge of the deflection of Abancay (Marocco, R., 1978) and is characterized by the presence of faults and folds oriented EW, NW-SE that affect the rocks of the Mesozoic and Cenozoic .

Tectonism above the stocks, this is evident because the failure of these anticlines not manifest in the intrusive rocks. The NNW-SSE compressional efforts originate EW fracture system that is evident mainly in the Yura Group quartzite that fracture in fault zones causing tectonic breccia.

Alterations

- **Early potassic alteration (Bt-mt-FK-py)**

Alteration is more exposed surface area and is affecting the bodies of diorite and diorite porphyry. Secondary biotite is the main mineral is mainly replacing pyroxene and amphibole. Is associated with magnetite, feldspar and pyrite. Magnetite and pyrite are characterized by replacing the mafic minerals (pyroxene and hornblende).

- **Main potassic alteration (FK-bt-ab-py)**

It manifests itself mainly to affect stocks monzonitic, monzodiorites, and the breccia dioritic intrusive. Has a structural control following fracturing and breccia zones. When applied to stocks and monzodiorites monzonitic alteration type is more pervasive, the plagioclase phenocrysts have been partially or completely replaced by potassium feldspar, the rock matrix has often been completely obliterated by alteration making it impossible to distinguish their original texture . When it affects the diorite breccias and the disturbance is manifested by way of polydirectional veinlets of K-feldspar, biotite, magnetite, pyrite and albite.

- **Late potassic alteration (FK-ab + py)**

This phase is largely controlled by fractures and applies without distinction to any of the intrusives. The potassium feldspar is associated with albite and they most commonly occur in veinlets, in other cases by way of patches partially obliterated the original texture of the rock, pyrite is subordinate and not always present.

- **Propylitic alteration (Close-ep-cac-py)**

It is characterized by over-imposed on the potassic alteration. Chlorites is replacing the biotite and pyroxene are also associated with calcite veins, pyrite-calcite veins and epidote. This association occurs in later stages of the various stages potassium. Surface is evident in the contact area of the breccia with the diorite porphyry intrusive at this you can see the replacement of crystals of biotite by epidote and chlorite.

- **Alteration sericite (ser-py + cz)**

Has been identified in the area of intrusive breccias affecting primarily the matrix and is associated with chlorite, clay (kaolin) and with varying content of pyrite, the presence of silica is restricted. Also presented on-imposed on the potassic alteration that affects the different intrusive phases, in this case we can see a replacement of potassium feldspar, plagioclase and biotite by sericite.

- **Argillic alteration**

Their presence is quite limited usually related to the host rocks of the structures has also been identified in the intrusive breccia zone adjacent to the alteration sericite. It is associated with fracture zones with limonite. It is pervasive and can identify a replacement of plagioclase by kaolin in many cases leading to completely obliterate the original rock texture.

- **Calc-silicate alteration**

It manifests itself in the areas of contact between carbonate rocks and the intrusive Utupara, is controlled by structures and associations have been identified prograde and retrograde over-imposed often making it difficult to identify

- **Prograde (Grn-he-wo)**

It is characterized by the presence of anhydrous minerals have been identified green and brown garnets (andradite and grossular) associated with diopside and wollastonite. The diopside is formed as a replacement of biotite and hornblende diorite. Wollastonite has replacement textures and more often filling fractures in crystals that can reach centimeter sizes.

- **Retrograde (cur-mt-esc + ca + ab)**

Mostly over-imposed on the prograde phase of destruction and is characterized by the presence of hydrated minerals formed at the expense of anhydrous minerals prograde stage. Actinolite is formed at the expense of pyroxenes prograde phase in thin-section petrographic study can identify that this replacement is partial in some cases there is pyroxene and amphibole found together..

Mineralization

- **Intrusive Breccia Zone**

Mineralization in the breccia is mainly disseminated and replacement filling pyrite and chalcopyrite disseminated recognizing both the clasts and matrix in the breccia and associated with magnetite and hematite. Filling and replacement mineralization occurs as veinlets of pyrite, chalcopyrite and magnetite.

- **Skarn Zone**

It consists of a series of bodies of magnetite in both elongated and low dip, the mineralization occurs along these bodies with dissemination of pyrite, chalcopyrite, pyrrhotite, magnetite. Pyrrhotite-magnetite association is characterized as replacement textures, pyrite and chalcopyrite are found to a lesser extent so widespread and in some cases in veins. The mineralization is associated with mineral phase retrograde actinolite, chlorite and albite.

- **Mantle zone (quartz structure)**

The robes are characterized by being placed in the quartzite, associations minerals are pyrrhotite, pyrite, chalcopyrite and oro. Están associated with iron oxides. In general, the textures are brecciated and replacement

- **Vein Zone**

They are thinner structures consist of quartz veins with iron oxides, pyrite and magnetite, the textures are mostly brecciated and show a cavernous appearance. In other cases the associations polymetallic mineralization is pyrite, chalcopyrite, galena, iron oxides and manganese. In both cases the host rock is a diorite which is argillizada and fractured.

Discusión

The porphyritic complex (Cu-Au) is characterized by having a varied lithology, including clastic and carbonate sequences of Mesozoic age which are intruded by an igneous polyphase system has evolved from intermediate stages in the pre-mineralization characterized by bodies diorite to acidic phases of mineralization stage presence and monzodiorites monzonites. Faults oriented NNW-SSE and NE-SW control alteration and mineralization. The potassic alteration is dominated with over-taxation of sericite and propylitic phases. We have identified three main stages of hydrothermal alteration: Stage

I characterized by an early-stage potassium-bt-mt-py + cpy FK, the Stage II is characterized by a phase assemblage main potassium FK-bt - ab - m - py - cpy and related to the occurrence of a breccia intrusive intrusions and monzonitic NS, the Stage III characterized by late-stage potassic assemblage with FK-ab + py, was notorious in this case the structural control related to smaller structures.



Photo 3.22: Structure of white quartz with sulfides in quartzite. Note the host rock altered to sericite. Interior Utupara old mine.

Figure 3.23: Breccia magmatic heterolytic and biotitic matrix. Chalcopyrite and pyrite disseminated in matrix. Feldspar veinlets.



Photo 3.24: Area of oxides in skarn, chrysocolla, malachite. Chapi-Chapi area.

Photo 3.25: monzonite porphyry dike, crystals <10 mm of potassium feldspar. The dike is cutting magmatic breccia.

9.- Vicinity of LAS BAMBAS

Location

The area is located in the district of Coyllurqui, Cotabambas province of Apurimac department. The central coordinates are 786670E, 8445440N and an altitude of 4400 meters. (Fig. 3.10).

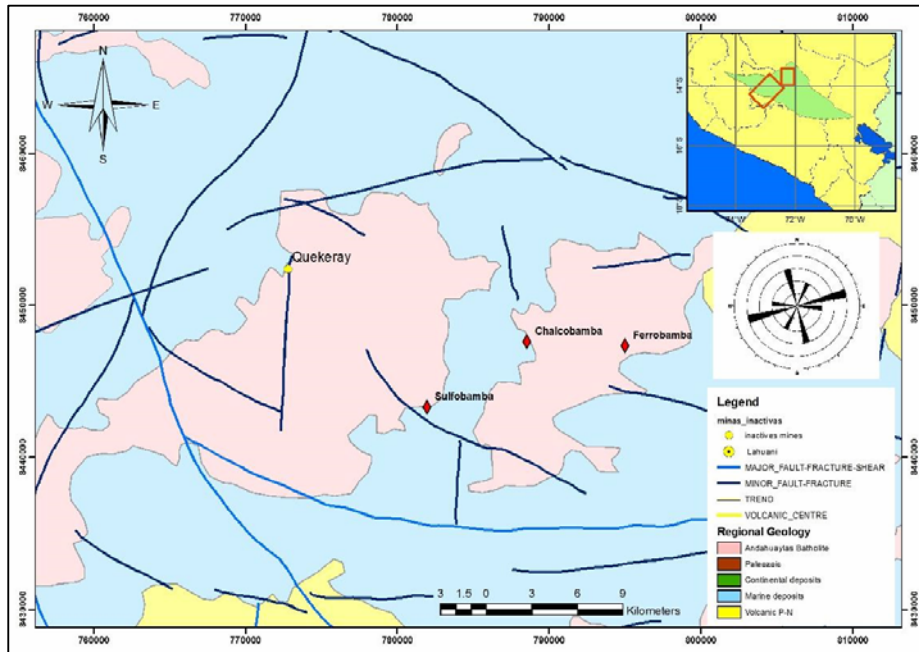


Figure 3.10: Las Bambas Location Map.

Geology

Lithology

- **Limestone:** dark gray-colored outcroppings, fine texture micrite with veins of calcite. In zone is brecciated by faulting. It is common for these fractures sigmoid veins filled by calcite.
- **Porphyritic monzonite:** intrusive characterized by a gray with pink hue. The texture is porphyritic. Minerals predominate as plagioclase (<5 mm), feldspar (<5 mm) and quartz to a lesser extent. Hornblende biotite and magnetite as accessory minerals.
- **Diorite:** This pluton is characterized by a light gray color, the texture is medium grain phaneritic, essential minerals are plagioclase <3mm and subordinate feldspar. The main accessory mineral is hornblende.

- **Porphyritic dacite:** Stock hypabyssal colored light gray, porphyritic texture with plagioclase crystals <5 mm, subordinate feldspar and quartz. The matrix is aphanitic texture.
- **Marble:** Characterized by dark gray to gray color. It is produced by metasomatism between the intrusive diorite and monzogranite with limestone. The degree of recrystallization is intense.

Structural

We have identified three structural systems whose directions are N75E/70SE, N20W/70NE and N25E/70SE. Quartz veinlets halos potassium and copper oxides are controlled by the system with inclination N70-75E and dip 60-70 SE.

Alterations

- **Potassic alteration**
This phase is largely controlled by fractures (veinlets) and applies without distinction to any of the intrusives. The potassium feldspar is associated with quartz and both are presented mostly as halos in quartz veinlets.
- **Propylitic alteration**
Chlorites are replacing the biotite and pyroxene in monzonites and diorites. They have also been identified in veins with the assemblage quartz-chlorite-magnetite.
- **Sericite alteration**
Affects the intrusive diorite and monzonite. Manifests replacing feldspar and plagioclase crystals in many cases obliterating the original rock texture.

Mineralization

The identified mineralization is restricted to quartz veins with pyrite and chalcopyrite. In the diorite you can see veins and veinlets of copper oxide silica in fractures (chrysocolla and malachite) and iron oxides produced from sulphide (pyrite, chalcopyrite).



Photo 3.26: veins of quartz-magnetite-actinolite alteration in monzonite with phyllic (CZ-ser-py).



Photo 3.27: halo quartz veinlets of K-feldspar in diorite.

Ore Geochemical

Table N° xx.- Gold Ore Geochemical Analysis in Andahuaylas – Yauri Batolith.

Sample	Au (gr/Tn)	East	North	Mineral occurrence
GE24 R0909-001	0.770	735437	8411586	Utupara
GE24 R0909-002	0.055	735437	8411586	Utupara
GE24 R0909-003	0.053	733419	8410420	Utupara
GE24 M0909-004	0.046	714080	8408684	carretera a Mollebamba
GE24 R0909-013	0.026	729718	8395718	Trapiche
GE24 R0909-014	0.065	729484	8395809	Trapiche
GE24 R0909-015	0.028	729076	8396198	Trapiche brechas
GE24 M0909-016	0.037	729076	8396198	Trapiche brechas
GE24 R0909-018	0.030	728858	8395951	Trapiche brechas
GE24 M0909-019A	0.246	716608	8399417	camino a Mina San Diego
GE24 R0909-020	0.019	716608	8399417	camino a Mina San Diego
GE24 R0909-022A	0.023	716788	8399170	camino a Mina San Diego
GE24 M0909-024	0.074	717585	8399120	Mina San Diego
GE24 R0909-025	0.015	719842	8413041	Proyecto Antilla
GE24 R0909-026	0.012	719970	8413214	Proyecto Antilla
GE24 R0909-028	0.016	719248	8412377	Proyecto Antilla
GE24 R0909-029	0.012	719248	8412377	Proyecto Antilla
GE24 R0909-030A	0.006	717063	8483867	Camino a Andahuaylas
GE24 M0909-038	0.824	769855	8384305	Camino Azuca
GE24 M0909-041	5..40	753233	8397186	Mina Santo Domingo
GE24 R0910-045	0.066	787166	8501066	Mina Yanamina
GE24 R0910-046	0.089	787055	8501070	Mina Yanamina
GE24 R0910-056B	0.033	792385	8503029	Prospecto Llocllacsa
GE24 R0910-062B	0.042	786554	8482576	Cluster de Cotabambas
GE24 R0910-063	0.036	786554	8482576	Cluster de Cotabambas
GE24 R0910-067	0.021	786587	8482640	Cluster de Cotabambas
GE24 R0910-068	0.049	786587	8482640	Cluster de Cotabambas
GE24 R0910-080	0.014	783911	8480329	Cluster de Cotabambas
GE24 M0910-085	0.060	785202	8423751	Cluster Las Bambas
GE24 M0910-091	0.876	197195	8402821	Cluster de Katanga
GE24 M0910-092	4.604	197789	8402352	Cluster de Katanga
GE24 M0910-095	1.064	197685	8403017	Cluster de Katanga
GE24 M0910-103	0.050	198324	8407146	Cluster de Katanga
GE24 M0910-104	0.041	198345	8407155	Cluster de Katanga
GE24 M0910-105	0.033	198345	8407155	Cluster de Katanga
GE24 M0910-109	0.373	228331	8369220	Cluster de Katanga
GE24 M0910-110	3.608	228331	8369220	Cluster de Katanga
GE24 M0910-111	3.685	228349	8360073	Cluster de Katanga
GE24 M0910-113	1.409	228409	8359974	Cluster de Tintaya

Datum: WGS 84 – 18 zone. The gold was analyzed for Fire Assay with Atomic Absortion for concentration less to 5 ppm and Fire Assay with Gravimetric for concentration bigger than 5 ppm.

Ore Geochemical

Table N° xx.- Polimetalic Ore Geochemical Analysis in Andahuaylas – Yauri Batolith.

Method	Coodinate		Deposits	ISP-140	ISP-331	ISP-140	ISP-140	ISP-140	ISP-140	ISP-140	ISP-140	ISP-140
Sample				Ag	Ag	Cu	Cu	Fe	Pb	Pb	Zn	Zn
				AA	FA/GRAV	AA	AA	AA	AA	AA	AA	AA
	North	East			ppm	g/tm	ppm	%	%	ppm	%	ppm
GE24 M0909-016	8396198	729076	Trapiche brechas	4.4	--	8566	--	3.46	68	--	57	--
GE24 M0909-019A	8399417	716608	camino a Mina San Diego	>100.0	525	374	--	2.52	--	>10.00	137	--
GE24 M0909-038	8384305	769855	Camino Azuca	265.9	--	321	--	7.14	--	1.01	--	2.05
GE24 M0909-041	8397186	753233	Mina Santo Domingo	155.4	--	862	--	8.99	43	--	90	--
GE24 M0910-070	8482708	786727	Cluster de Cotabambas	9.0	--	--	2.00	>10.00	43	--	428	--
GE24 M0910-073	8482708	786727	Cluster de Cotabambas	1.1	--	--	1.43	>10.00	25	--	208	--
GE24 M0910-085	8423751	785202	Cluster Las Bambas	8.3	--	--	6.19	1.21	114	--	81	--
GE24 M0910-100	8403017	197685	Cluster de Katanga	7.0	--	--	1.42	8.02	217	--	910	--
GE24 M0910-103	8407146	198324	Cluster de Katanga	1.8	--	--	5.11	>10.00	37	--	272	--
GE24 M0910-104	8407155	198345	Cluster de Katanga	4.4	--	1492	--	>10.00	30	--	134	--
GE24 M0910-105	8407155	198345	Cluster de Katanga	4.8	--	6480	--	>10.00	61	--	430	--
GE24 M0910-109	8369220	228331	Cluster de Katanga	19.6	--	1209	--	3.54	4184	--	2343	--
GE24 M0910-110	8369220	228331	Cluster de Katanga	12.4	--	4544	--	4.55	1946	--	429	--
GE24 M0910-111	8360073	228349	Cluster de Katanga	21.0	--	5390	--	6.86	9847	--	522	--

Datum: WGS 84 - 18 zone. The silver was analyzed for Atomic Absorption for concentration less 100 ppm and for Assay Fire with gravimetric for concentration bigger than 100 ppm. The Cu, Fe, Pb, Zn was analyzed for Atomic Absorption with different upper detection limited.

4.- REGIONAL GEOCHEMICAL (STREAM SEDIMENT)

Introduction.-

The regional geochemical work of stream sediment realized by INGEMMET in the 2 and 3 belts have served as a tool to differentiate geochemical domains and thus associated with possible petrogenetic domains

In this way was used the regional geochemical of stream sediment as a tool to determine metallogenic provinces (Rivera & Condori, 2010). The objective of this interpretation was to determine variations in the regional background and associate to possible metallogenic provinces, which may have different potential for mineralization.

The regional geochemical interpretation by the background controls resulted in the interpretation of two different metallogenic provinces known as the domain of the internal arc and the main arc (Clark et al., 1990).

By regional geochemical interpretation can also infer some regional fault systems such as: the USA fault systems (Urcos - Sichuan - Ayaviri) that behaves as a high structural separating internal arc domain of the main arc domain (Clark et al., 1990). Other fault systems can also be inferred, such as Puyentimari and Patumburco that behaves as transform faults associated to Abancay deflection (Carlotto et al., 2006) (Fig. 4.7).

In conclusion by this new regional interpretation demonstrated the use of regional geochemical as a tool to differentiate metallogenic provinces and their possible application to exploration.

At the end of this regional interpretation you can see some isovalue maps of the Andahuaylas - Yauri Batholith domain (Cu - Au - Mo), overlaid with locations of major mineral occurrences. Local Isovaloric maps of the Jalaoca and Colca areas also were interpreted (Au - Cu - Mo).

Isovaloric maps were made using data from regional stream sediment by the Geosoft program (modulo Chimera), using the minimum curvature method, then the method of smoothing and finally for better contrast was given the appearance of shadows. These isovaloric maps for a better compare were added shapes of intrusive rocks and regional fault systems, in order to provide better space correlations (Fig. 4.6).

Also was made 3D isovaloric maps in order to get a better view of the changes in regional background (Fig. 4.11)

4.1 REGIONAL PETROGENETIC DOMAINS INTERPRETED BY STREAM SEDIMENT

Main Arc Domain.-

This petrogenetic domain is characterized for has a potential related to the mineralization of Cu - Au - Mo - Fe \pm (Pb - Zn - Ag). Alkalinity vs silica indicate that this domain is related to a calc-alkaline magmatism with medium to high potassium content, while the alumina indicate that this domain lies within the metaluminous environment.

Both types of geochemical classifications are related with magmatism in subduction environment whose magmas were ascending through large regional faults. Some of these magmas have a little crustal contamination, and other major crustal contamination, and this can be seen in the potassium content.

In the figures 4.1 and 4.2 can be appreciated as isovaloric maps of calcium and strontium defined very well the limit of the petrogenetic environments. It is known that strontium is a member of the alkaline earths of group IIA (Be, Mg, Ca, Sr, Ba and Ra). The ionic radius of strontium is 1.13 Anstromg, so higher than the calcium (0.99 Anstromg). Strontium is also a dispersed element that occurs in calcium-containing minerals such as plagioclase, apatite and calcium carbonates.

Through many petrological studies it is known that in the domain of the internal arc there are more intrusive rocks with a greater abundance of plagioclase and mafic minerals that have in their crystal lattices a high concentration of calcium, which can be replaced by strontium.

Internal Arc Domain.-

This domain is characterized for have a Sn - W - Mo - U and REE potential. Alumina graphics classify the internal arc rocks as peraluminous.

On the other side in figures 4.3, 4.4 and 4.5 can be clearly appreciated as the aluminum; lanthanum and beryllium elements define the domain of the internal arc. This domain using geochemical studies of rocks is assigned a peraluminous signature, perhaps related to processes of anatexia or strong crustal contamination.

Then it is clear that the aluminum element defined very well the internal arc domain and this is because the firm is peraluminous ($Al > Na + K + Ca$) and corresponds to the igneous rocks that outcrop in the study area. On the other hand the lanthanum element is a light rare earth, whose high concentration is related to igneous rocks with moderate to

strong magmatic differentiation (rhyolite or granite), as Macusani tuffs or some facies of the Carabaya Batholith .

Goldschmidt and Peters (1932) recognized that beryllium could be enriched in the crust, because beryllium behaves as a lithophile element and has a geochemistry behavior very similar to aluminum. Nowadays is estimated to crustal an average 3 ppm, which represents an enrichment of 50 times in relation to the contents of the primitive mantle.

Beryllium can be found in the majority of minerals, including important rock-forming minerals, with a very regular concentration of up to 10 ppm or even less, rarely exceeding 100 ppm. Then beryllium is an element incompatible in many geological systems. However, some minerals have reported that incorporate substantial amounts of beryllium. The principal beryllium mines are related to pegmatites rocks, but there is information of occurrence of beryllium in rocks not pegmatites related to peraluminous magmatism. Several examples are given on the origin of uranium deposits and most of them are related to deposits that occur in environments strongly to weakly peraluminous, for example: beryllium-enriched rhyolites (Macusani), beryllium- enriched granite (Cordillera Carabaya and its possible continuity in the Permo - Triassic granites).

This is one of the reasons why beryllium defines very well the contour of the isovaloric maps of stream sediment in the internal arc domain. Although there are some high concentrations of beryllium and lanthanum in the southern zone related to volcanic rocks moderately to highly differentiated, such as the Santa Rosa dome.

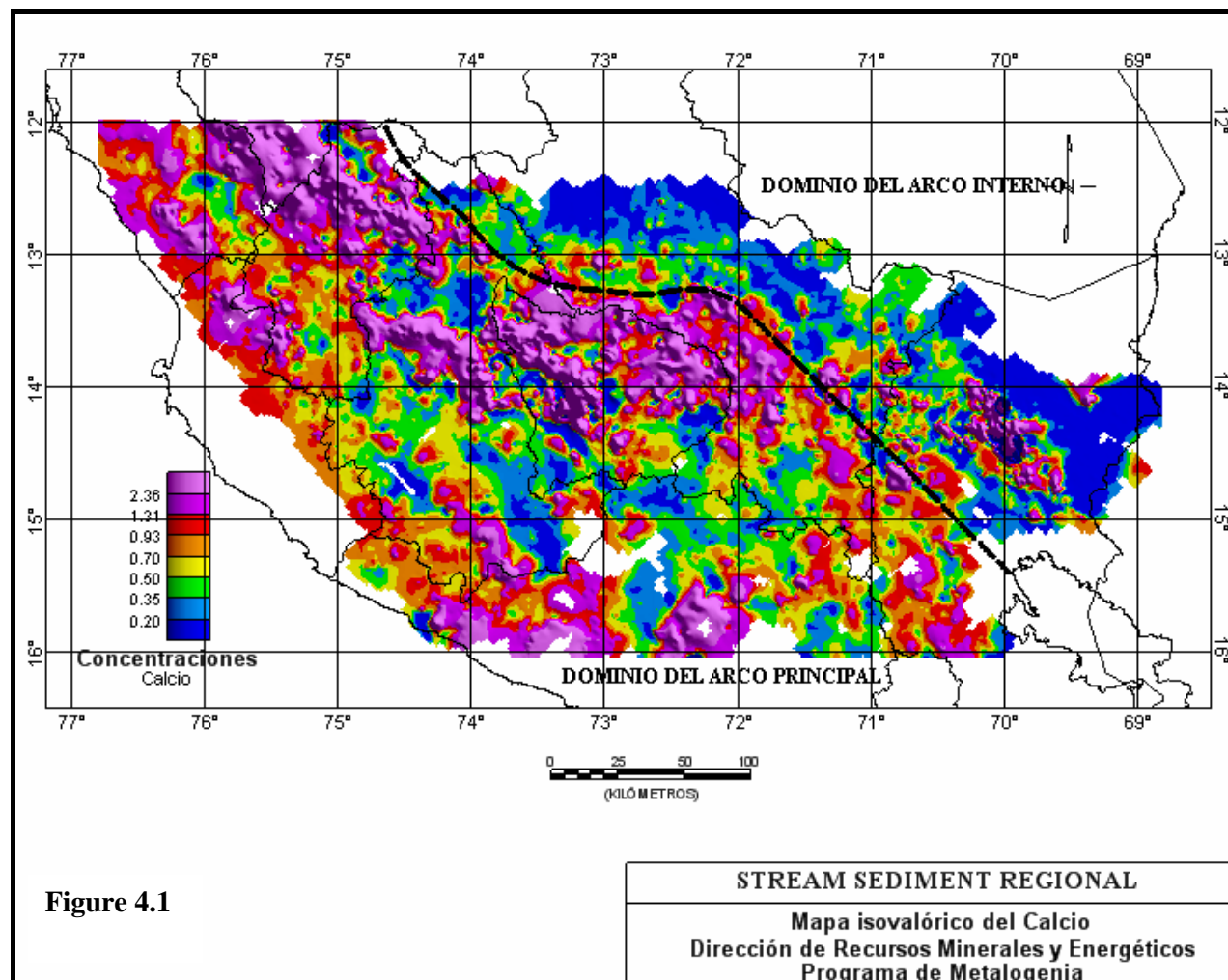


Figure 4.1

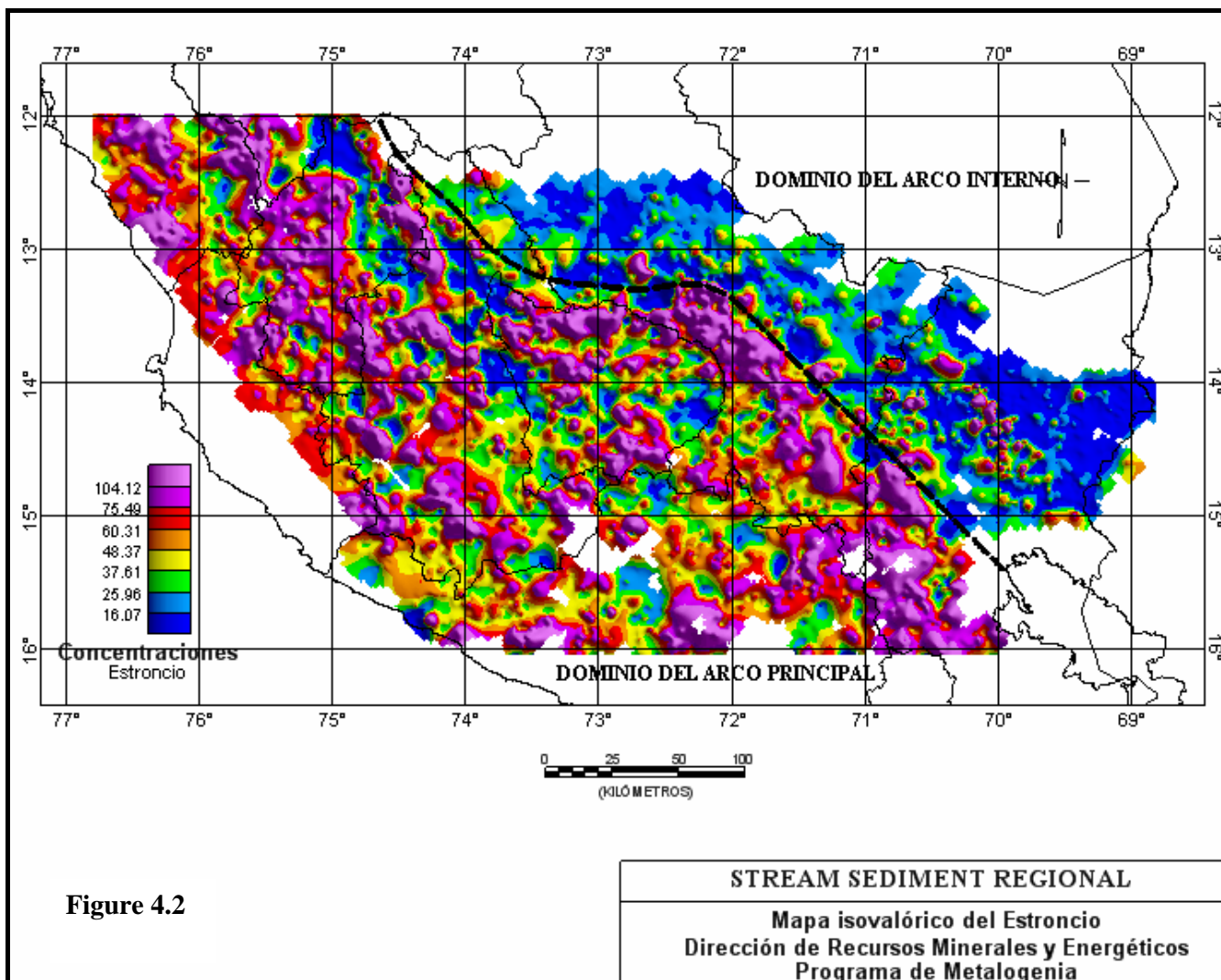
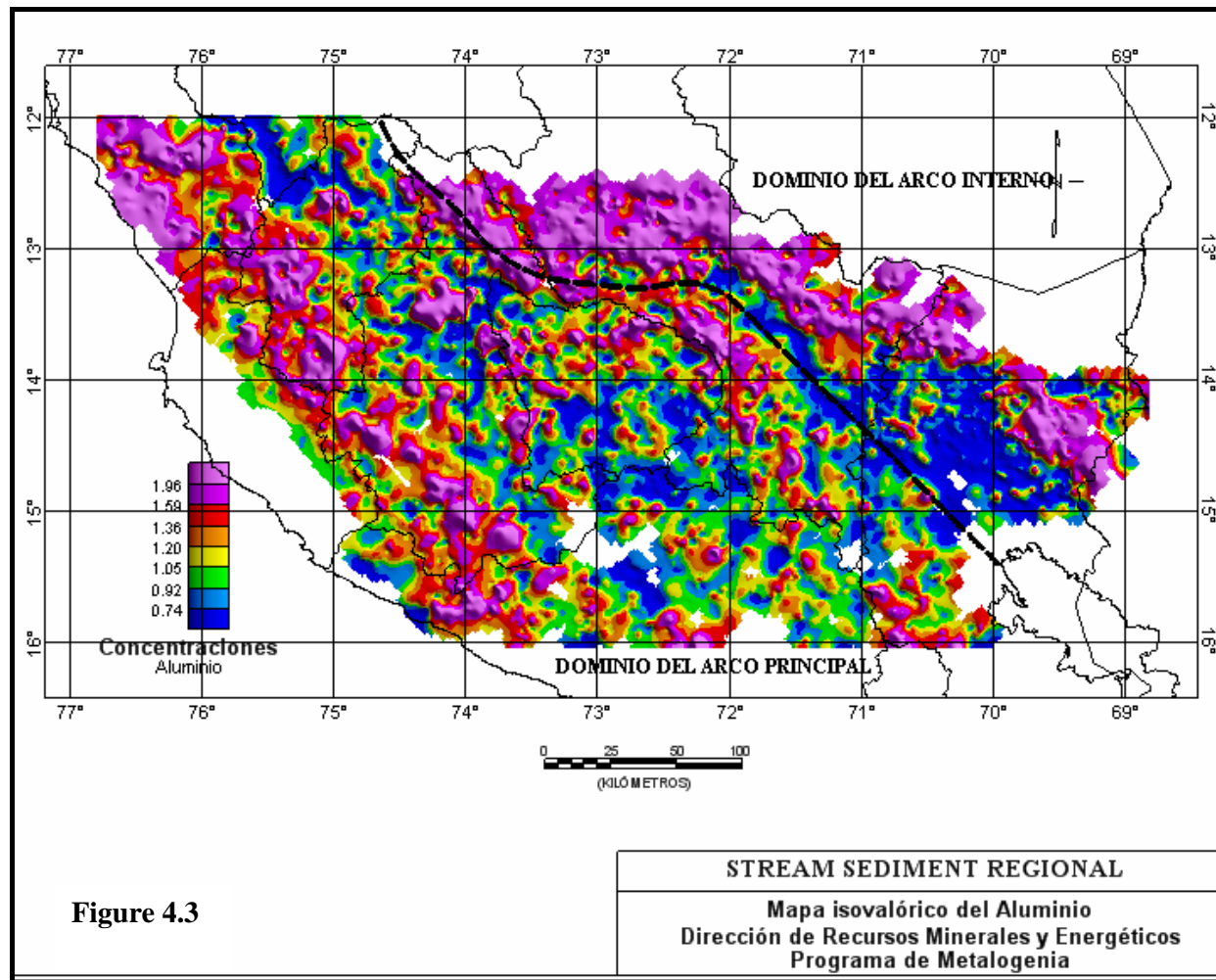


Figure 4.2



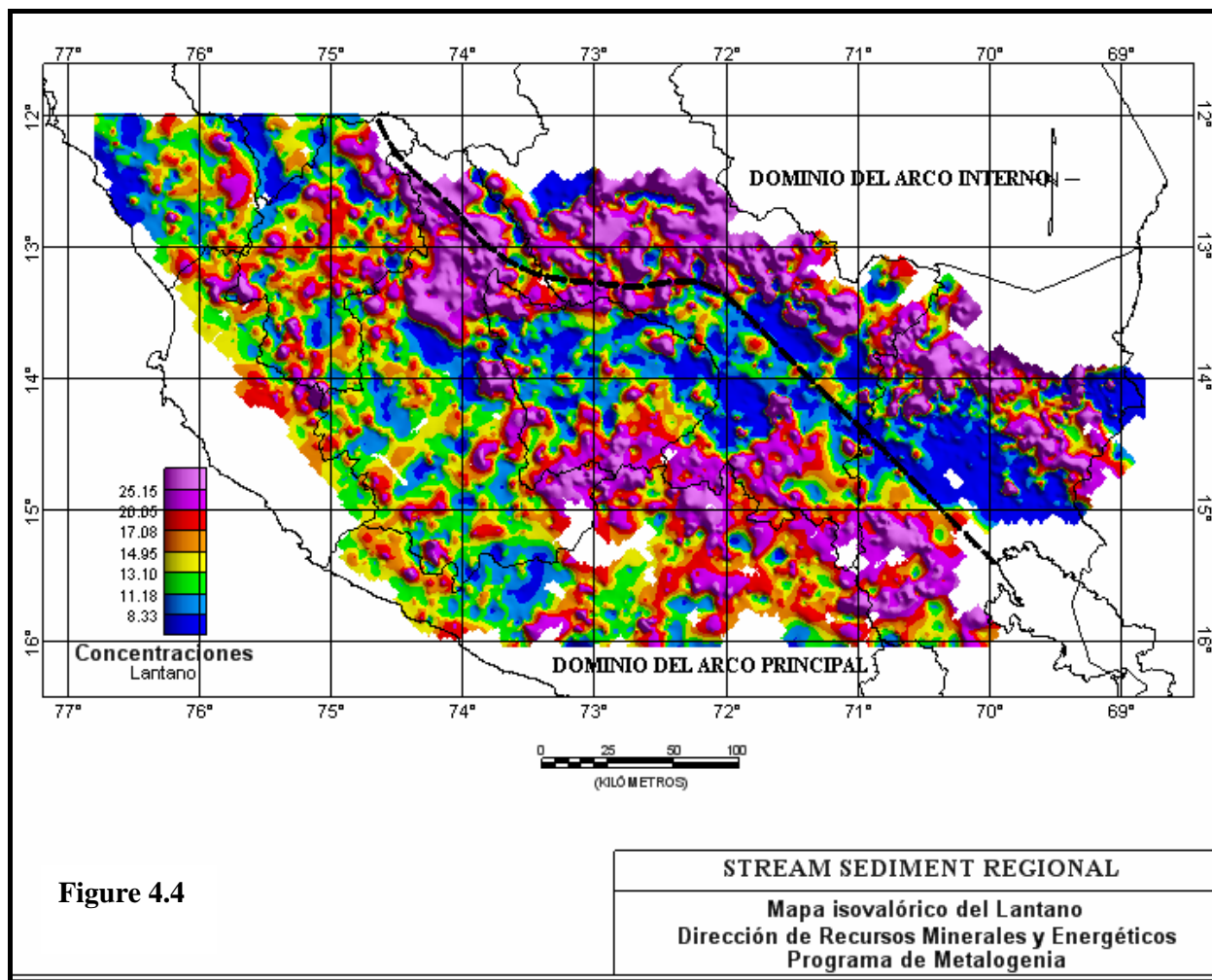
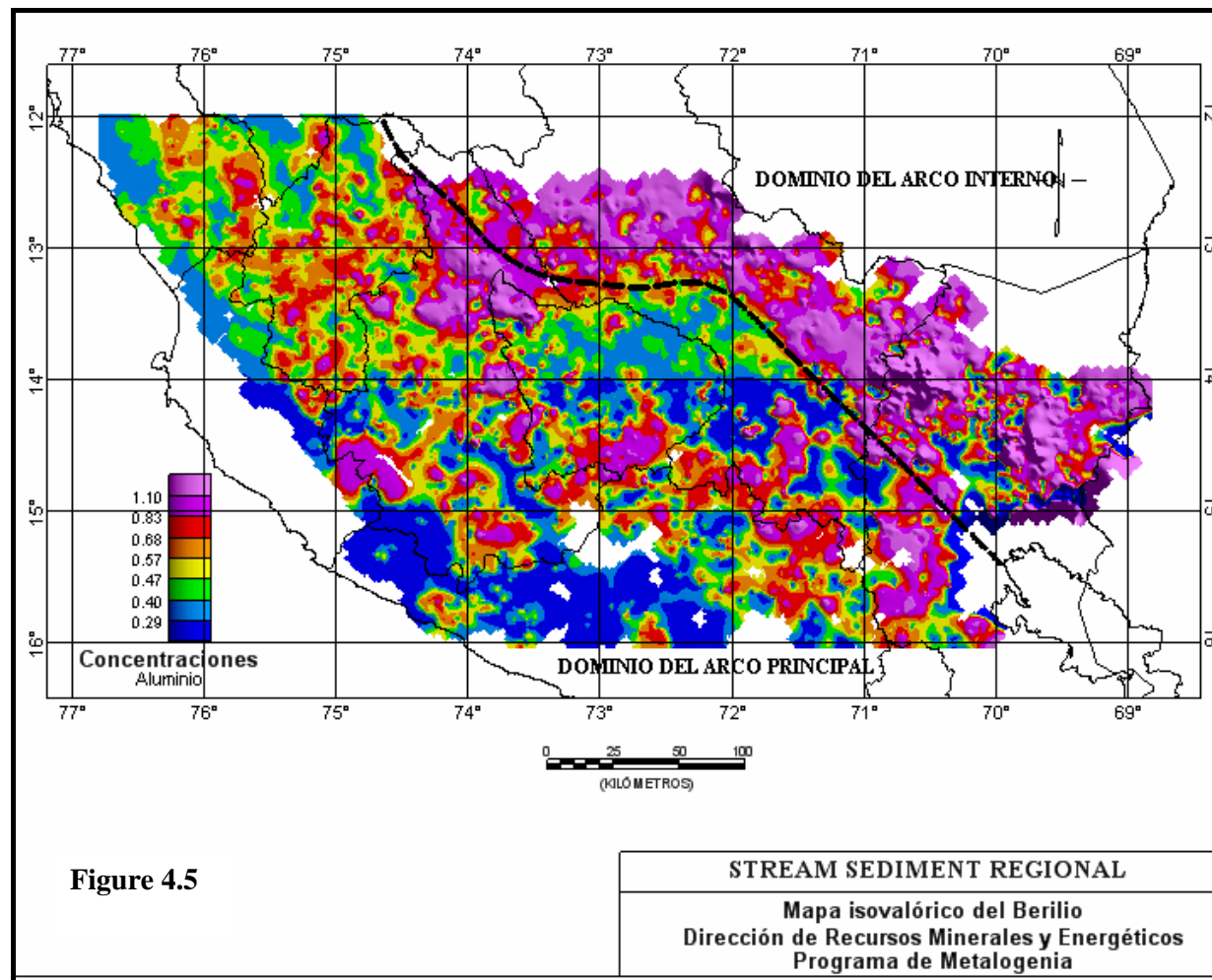
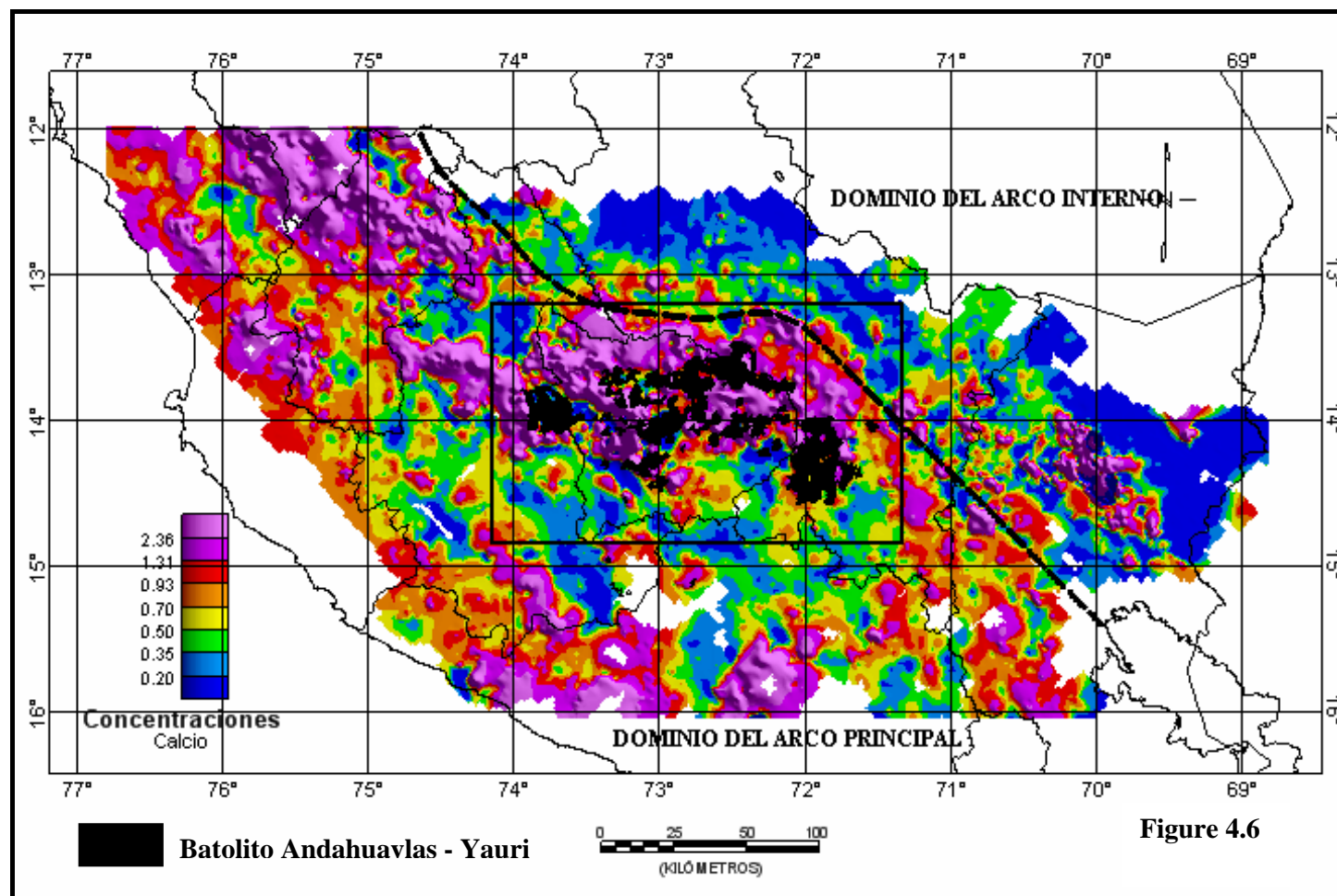


Figure 4.4





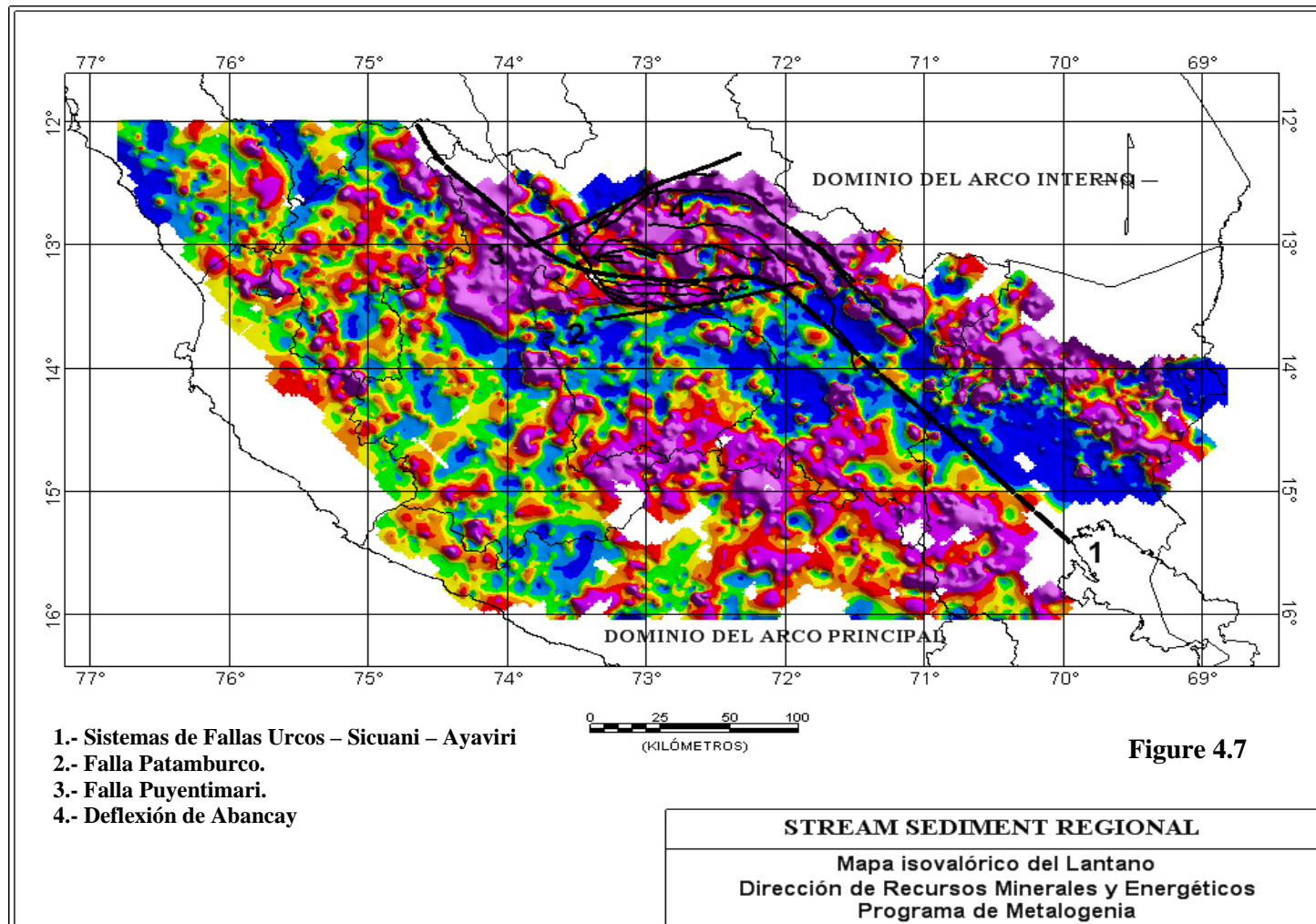


Figure 4.7

4.2 GEOCHEMICAL OF STREAM SEDIMENT ANDAHUAYLAS – YAURI BATHOLITH

The geochemical values of the stream sediment samples have allowed to elaborate isovaloric maps concerning to the Andahuaylas - Yauri Batholith. Knowing the potential of the batholith by means of the inventory of the mineral deposits has been interpreted the copper, gold, molybdenum maps isovalóricos (Fig. 4.8, 4.9 y 4.10) with the purpose of correlating the high concentrations of these chemical elements with the location of the deposits in the Andahuaylas - yauri domain of the and to be able to them to correlate with some other areas of interest.

The copper isivaloric map shows a clear tendency of the areas of more concentration with strike SE - NW coinciding spacely with the Andahuaylas - Yauri Batholith outcrops. These areas of more concentration involve big groups of deposits as: the Tintaya, Katanga, Las Bambas, and Cotabambas cluster. But it is also clear that exist a great quantity of small anomalies that indicate vestiges of some mineral deposit no yet discover.

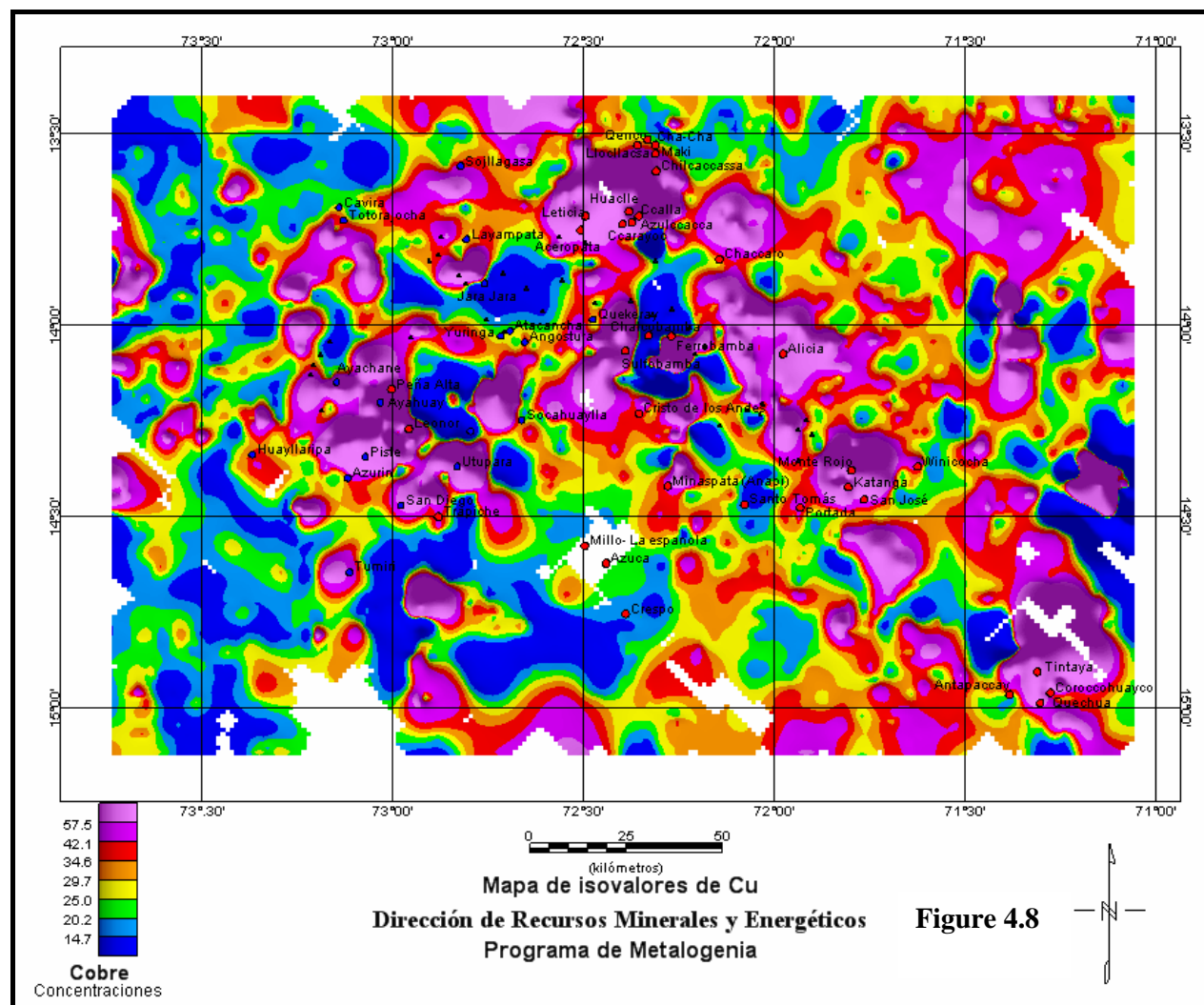
On the other hand the gold isovaloric map shows a clear tendency in SE - NW strike much more straight that the Copper tendency. Their geochemical anomalies coincide with important cluster as Cotabambas where are located the Cu - Au porphyries. This tendency also includes the Tintaya, Katanga and Bambas cluster. A very important observation with regard to the gold is the anomaly that form the group of occurrences that are located in the surroundings of Utopara, Trapiche and Peña Alta. Highlighting that most of the occurrences is related to gold veins in carbonated rocks, those which at the moment are being worked handmadely. The same as the copper the study area shows important geochemical anomalies that deserve more studies to the detail.

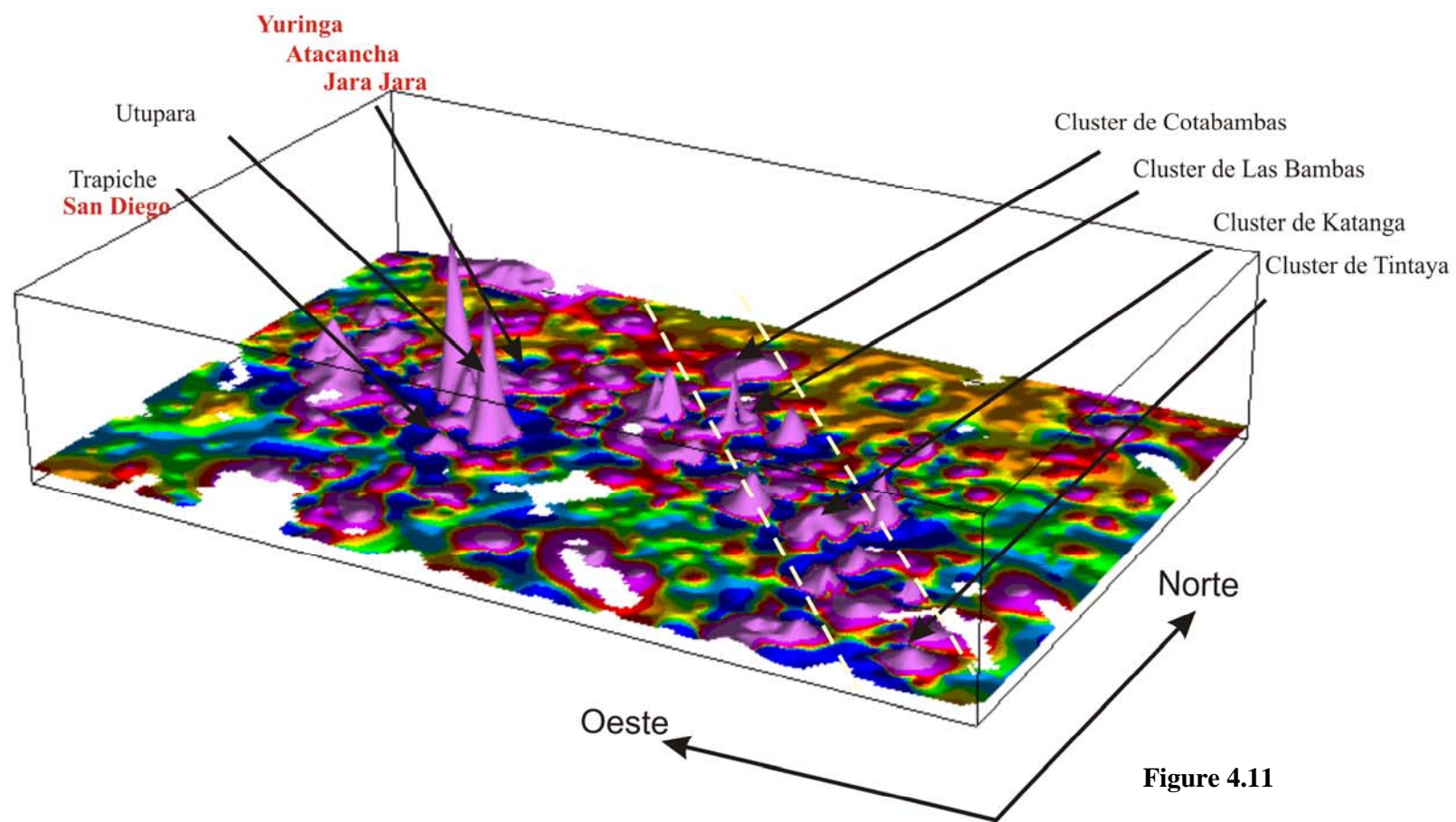
The Mo isovaloric map shows a distribution of anomalies completely different to that of the Cu and Au maps. Their higher values are related to an area among San Diego - Trapiche going by Utopara until the Cotabambas cluster. We can observe as the Cristo de los Andes - Haquira occurrences coincides with the Mo geochemical anomalies. Toward the north of the Katanga cluster and east of The Bambas Cluster is observed a wide anomalous area to which any occurrence is not still associated.

The geochemical correlations among the Au - Cu and Mo indicate a better correlation for the Au - Cu. The south part of the Andahuaylas - Yauri batholith outcrop volcanic rocks moderately

differentiated where until the moment have been discovered important deposits as Azuca, Millo and Crespo.

In the 3D graph it is observed clearly the anomalies belt that form the Tintaya, Katanga Las Bambas cluster. This group of deposits belongs to one age and they are aligned in sense SE - NW, then with these evidences we could infer the possible existence of a regional fault that controlled the location of these mineral deposits.





4.3 GEOCHEMICAL OF STREAM SEDIMENT ON THE COLCA AND JALAOCA ZONES

Product of the combined investigations between INGEMMET and KIGAM some areas were determined with geologic potential as Jalaoca and Colca. These areas are inside the Batolito Andahuaylas - Yauri domain very near some important deposits as Utupara and the Cotabambas cluster, respectively.

By means of the stream sediment isovaloric maps stream it is observed that boths areas regionally are related to anomalous zones (Fig. 4.12, 4.13, 4.13, 4.14, 4.15, 4.16 and 4.17). The Colca area is inside the influence of the Cu - Au anomalies of the Cotabambas cluster, while the Jalaoca area is inside the domain of the Au - Cu - Mo anomalies of the deposits of Utupara - San Diego and Trapiche..

For a better visualization were made isovaloric local maps, with smaller quantity of stream sediment samples and was the expected the isovaloric local maps local are not identically similar to the regional maps.

On the local isovaloric maps of the Colca area, it is still observed a strong Cu - Au anomaly, while the molybdenum is only restricted to the highest parts on the Cotabambas cluster. The local isovaloric maps of Jalaoca show that this area is surrounded by strong Cu - Au and Mo anomalies, coinciding with the mineralization type of the mineral deposits that surround him.

Both areas are free of mining concessions and the geologic characteristics are very similar to that of the neighboring deposits. The mineralization evidences in surface check the potential of the areas.

It should take in consideration that the quantity of samples that define to these areas like interesting are very little, it is recommended a geochemistry prospecting work very more detail.

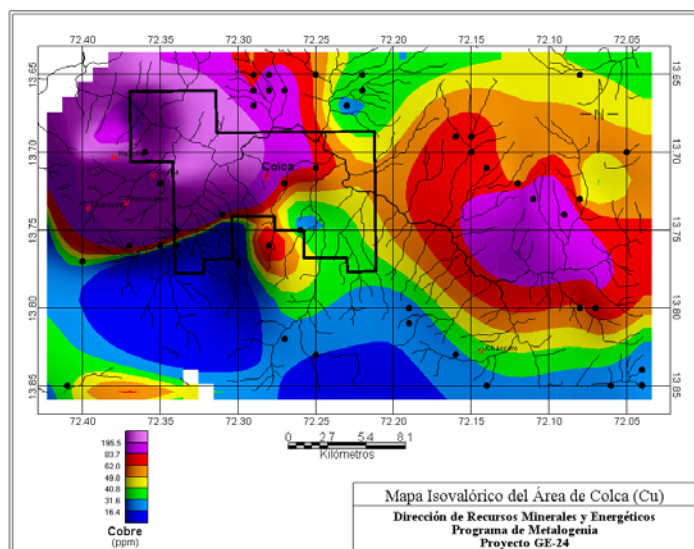


Figure 4.12

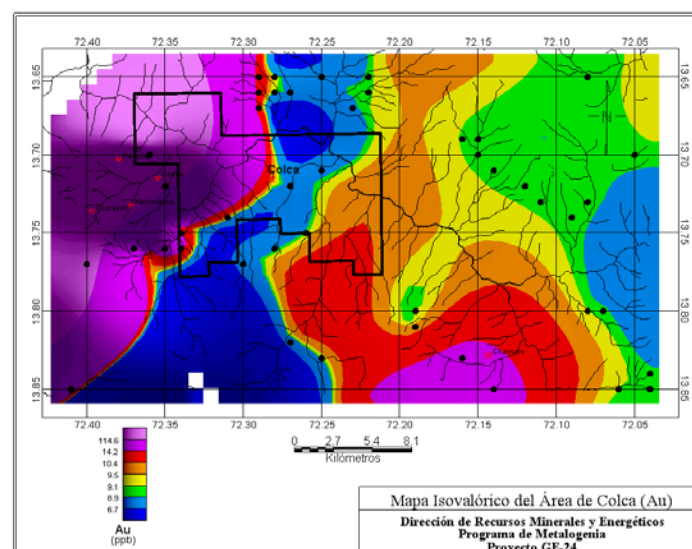


Figure 4.13

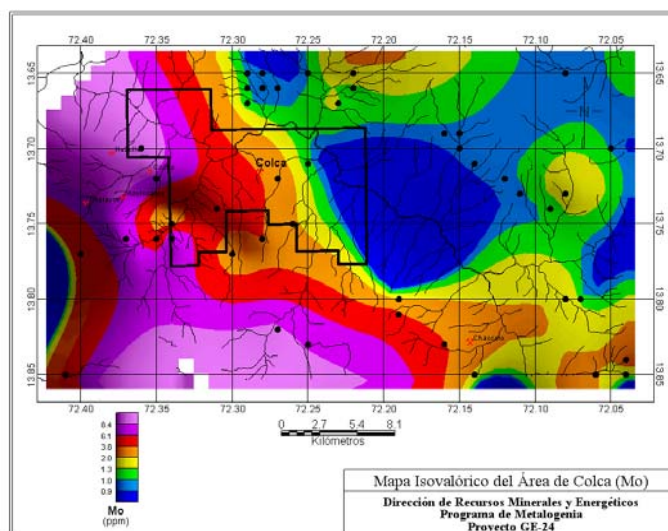


Figure 4.14

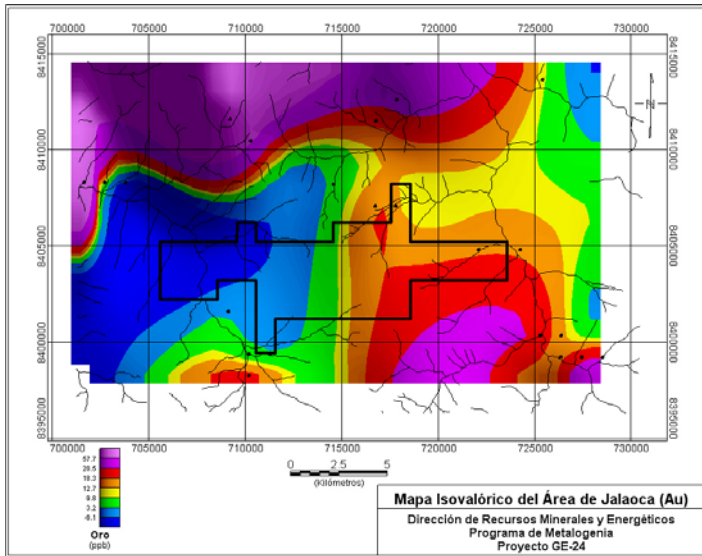


Figure 4.15

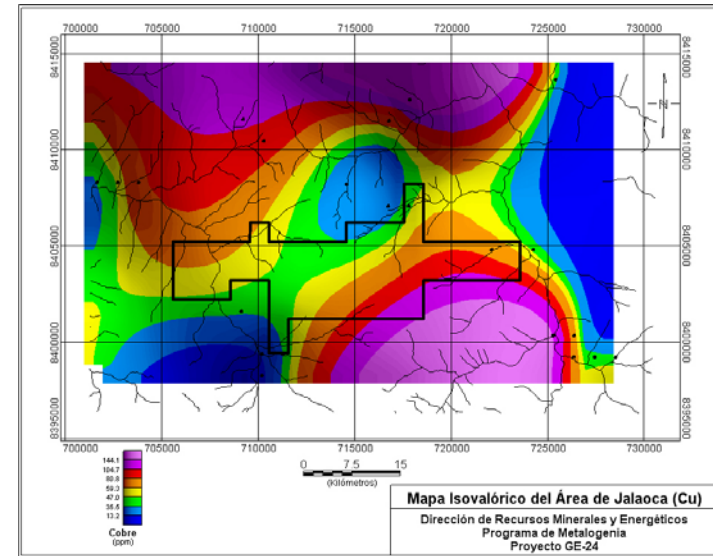


Figure 4.16

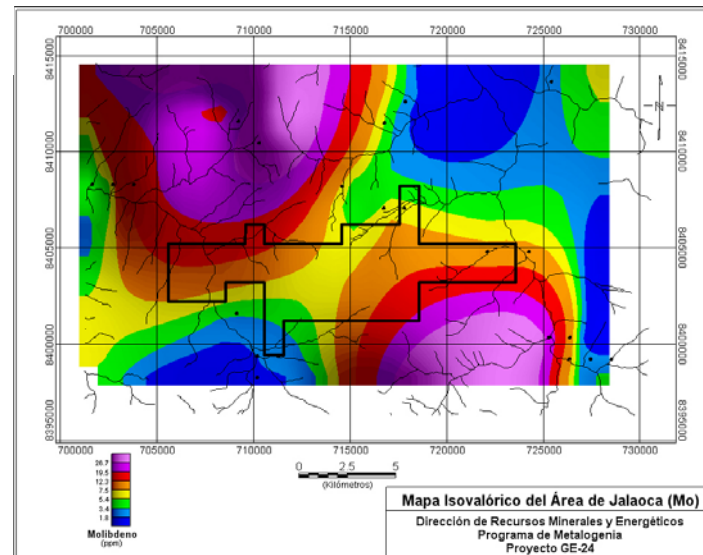


Figure 4.17

5.- Geochemistry of Rocks and Petromineralogy

Introduction.-

Today is well known the role of rock geochemistry in mining exploration. Over the years this geological tool has been strengthening both from the standpoint of analytical techniques, as well as from the standpoint of interpretation.

Multielement analysis opened the door to the understanding of many elements that time ago it was impossible to know. The accuracy and precision of these analytical techniques allowed to know much better the geochemical composition of rocks.

Currently it is not a secret that these multielement packages are used by exploration geologists not only from the quantitative point of view but also from the point of view of the reconstruction of geotectonic paleoenvironments.

Each geotectonic environment has a unique geochemical signature of major elements, trace and rare earth. The major elements usually show us the type of magmatism, whereas the trace elements and rare earths are used as geotectonic markers. Known these features are possible to infer the geo-economic potential of magmatism in the study and thus able to better direct exploration campaigns.

It is very important to remember that for an effective geochemical interpretation it always has to be related to petromineralogic studies. These are two tools that are closely related and together enable a better chemical - mineralogical interpretation, so that the interpretation of geochemical analysis should be reflected in the petro-mineralogy studies. So it is very important to note that on these arguments is edited the next chapter.

The classification of rocks using geochemical analysis often differs from the classification of rocks using the Streckeisen diagram (1976). As an introductory point and as a clear example that is perhaps due to the Streckeisen diagram (1976) considers only the crystallized quartz within their classification, while the geochemical analysis considers the total silica within the analyzed rock which can also be found in the aluminosilicates (feldspar). Similarly, the Streckeisen diagram (1976) considers only the crystallized potassic feldspar, while geochemical analysis considered the total of potassium, which can also be found in the biotite and other minerals.

The study of the magmatism in the Andahuaylas - Yauri Batholith requires a thorough understanding of geochemistry and petro-mineralogy of various intrusive rocks outcrop in the study area. So that will attempt to correlate both types of classifications because both are important tools in the petro-mineralogy.

For the development of this investigation were used the geochemical software GCDkit and IGEPET.

In order to begin the first geochemical interpretation is very important to try to characterize the magmatism or try to identify the magmatic series from which derived the igneous rocks located within the study area. In this regard, the graphic of Le Bas et al., (1986) (Fig. 5.1), allowed to interpret that the domain of magmatism in the Andahuaylas - Yauri Batholith is subalkalic related to a subduction zone within a convergent margin.

The magmatismo in the Andahuaylas - Yauri Batholith (subalkaline) is totally different from magmatism occurred in the south in the Colque Batholith (Upper Eocene – Lower Miocene). This last is very rich in potassium (Mamani et al., 2004).

The positive correlation between SiO_2 (x axis) vs $\text{Na}_2\text{O} + \text{K}_2\text{O}$ (y axis) in different groups of analyzed rocks (see legend) indicate a deep magmatic differentiation from basic to felsic rocks. Perelló et al., (2003) interprets these two groups of rocks as two different magma pulses developed during the Eocene to Oligocene (48 to 43 Ma and 42 to 30 Ma, respectively).

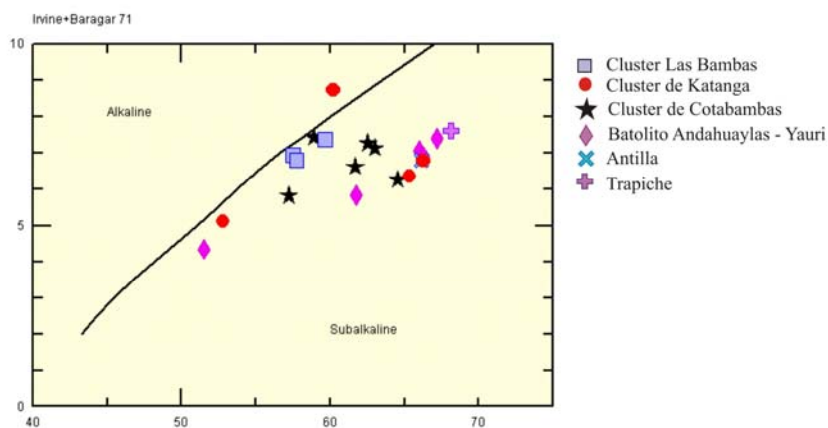


Fig. 5.1 SiO_2 vs K_2O Diagram (Le Bass et al., 1986)

Graphic AFM (Irvine & Baraga, 1971) (Fig. 5.2) allowed to interpret this magmatism had not none of their samples in the tholeiitic field, all samples fall within the calc-alkaline domain. The calc-alkaline characteristics are typical of active convergence margins very similar to calc-alkaline magmatism of the porphyry in Chile. It is also important to note that the development trend in this digram triplot ($\text{FeO}^* - \text{Alk} - \text{MgO}$) permit the interpretation that these samples have no relation to the type alkaline rocks (rich in $\text{Na}_2\text{O} + \text{K}_2\text{O}$) or at least in sodium feldspars. On the other hand, some samples have a clear trend of FeO^* which can be interpreted as rocks of deep origin possibly related to an oxidized magmatism more than reduced. Some samples that may be anomalous in the content of $\text{Na}_2\text{O} + \text{K}_2\text{O}$ really are not alkaline (Fig. 5.1) it is some type of crustal contamination or metasomatism, because the sample belongs to a skarn zone within the Tintaya Cluster.

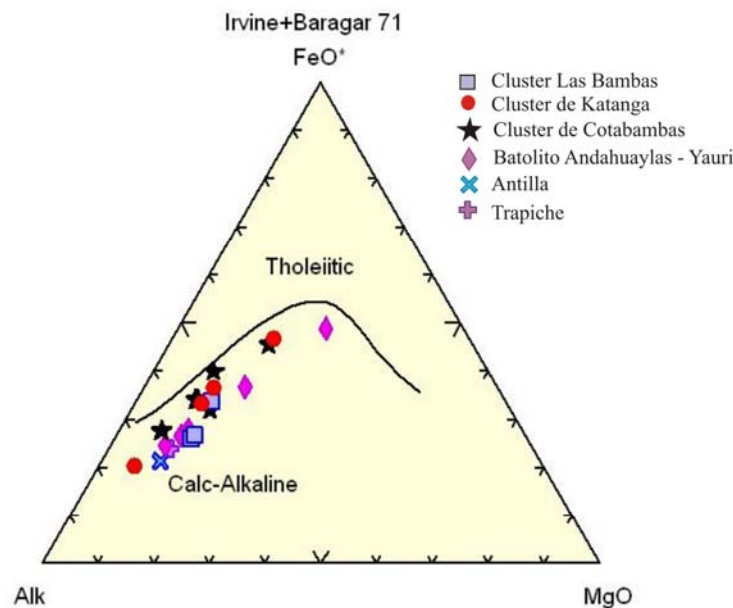


Fig. 5.2 AFM Diagram (Irving and Baragar, 1971)

Pecerillo & Taylor, 1976 (SiO_2 vs K_2O) graph (Fig. 5.3) is a tool that confirms previous interpretations. The content of potassium oxide (K_2O) is not so high to be considered within the alkaline- calcium or shoshonitic field, all the rocks fall into the subalkaline-calcalkaline field with medium to high potassium content. The different content of potassium and silica can be interpreted as different rates of crustal contamination and magmatic differentiation. It is also very clear that all groups of samples have a wide range of SiO_2 ranging from 51% to 68%, coinciding

again with the presence of mafic to felsic rocks, especially for the outcrops of the Andahuaylas – Yauri Batholith, but in general belong an intermediate composition magmatism (Fig. 5.3)

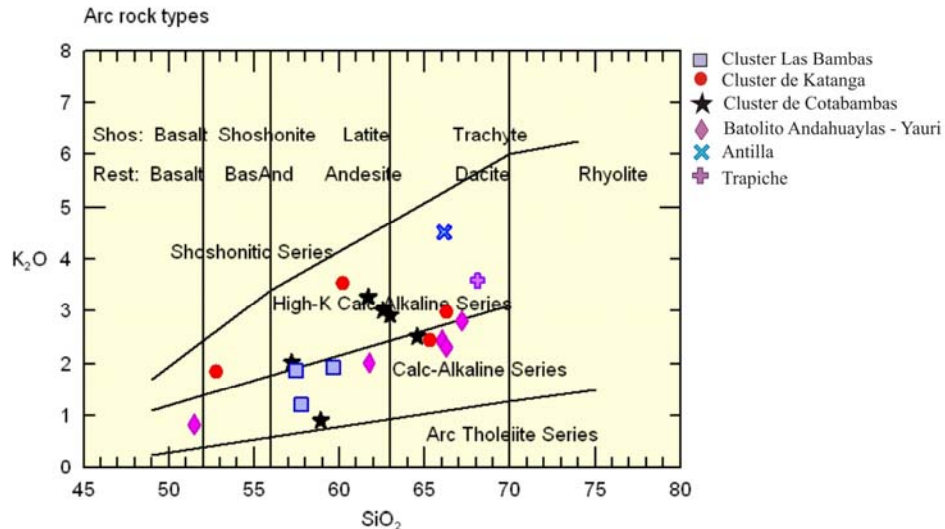


Fig. 5.3 K_2O vs SiO_2 (Pecherillo and Taylor, 1976)

Nomenclature of Intrusive Rocks

The graphic TAS (Cox et al., 1979) allowed to classify the various intrusive rocks within the study area. The Andahuaylas - Yauri Batholith have the samples with the broadest range of silica content ranging from gabbros, diorites, quartz diorites and granodiorites (Fig. 5.4). On the other hand the samples in the cluster of Cotabambas with a range of silica more restricted ranging from diorites, monzonites, quartz diorites and granodiorites. Field cutting relationships allow us to interpret the mafic rocks belong to the core of the batholith or first pulse, while the more differentiated rocks belong to a second magmatic pulse much more differentiated and possibly related to mineralization (Perelló et al., 2003). On the other hand Antilla and Trapiche projects are restricted to the granodiorite field, while the cluster of Katanga has a wide variation very similar to the Andahuaylas – Yauri Batholith, but with some monzonitic facies. Finally, the cluster of Las Bambas is presented as the most homogeneous group and is related to monzonite rocks

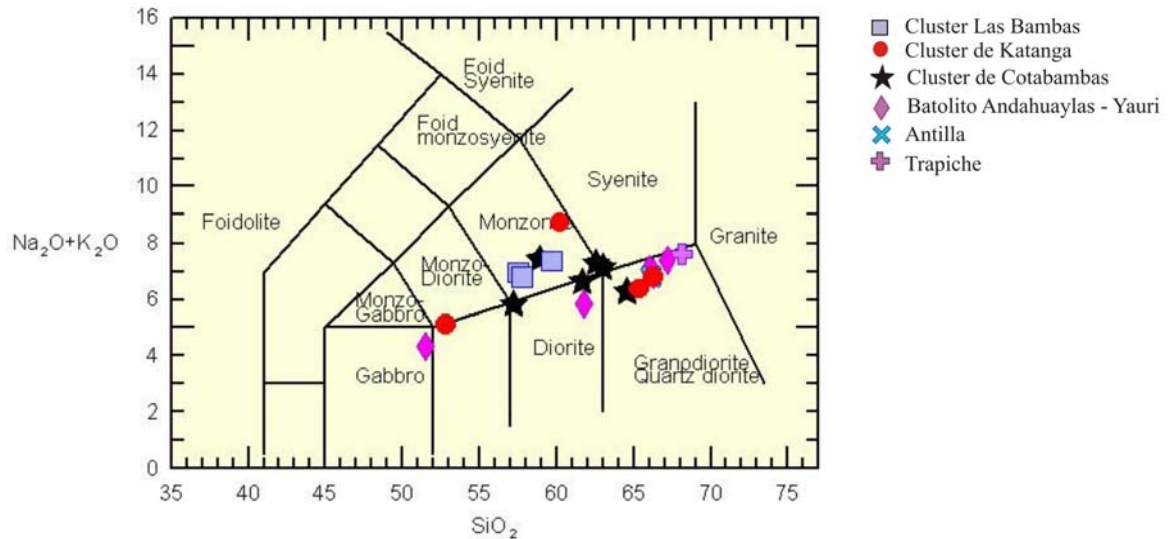


Fig. 5.4 $\text{Na}_2\text{O} + \text{K}_2\text{O}$ (Cox et al., 1979)

Andahuaylas – Yauri Batholith

Gabbros (sample GE24 - 031, photo 5.1a y b) were described macroscopically in the field as intrusive rocks with dark color (melanocratic) medium equigranular texture, plagioclase \pm cluster of ferromagnesian minerals. These rocks form the region rock around the cluster of Cotabambas and can be seen easily on the road Cotabambas - Colca.

While the sample GE24 - 033 (quartz diorite, Photos 5.2a y b) was described in the field as a medium grain intrusive rock and equigranular with plagioclase \pm biotite - horblenda - quartz. The sample GE24 - 035 (tonalite, photo 5.3a y b) in the field was described as an intrusive rock with medium-grain equigranular, leucocratic characterized by plagioclase - quartz \pm horblenda and biotite.

If you look in detail Fig 5.4 shows that there is no tonalite field within the TAS diagram (Cox et al., 1979), using a sample GE24 - 035 as ranked by modal analysis as tonalite plotted within the granodiorita field. As the tonalites and granodiorites have the same quartz content in the Streckeisen diagram, the only difference would mark the contents of crystallized potassium feldspar. Then to observe thin sections under the microscope shows that there is no more than 5% of potassium feldspar, therefore according to Streckeisen diagram these rocks belong to the tonalite field.

We interpret that the excess of potassium is probably because the biotite that occurs as clusters of ferromagnesian minerals.

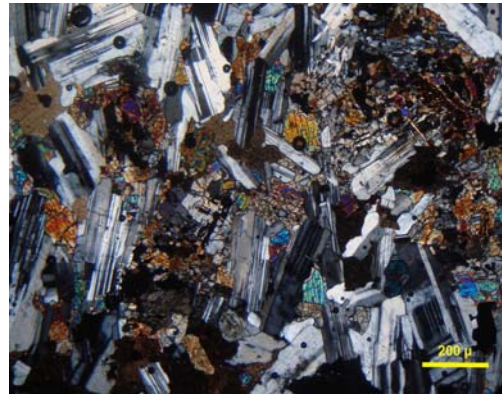


Photo 5.1a y b.- Sample GE24 -. 031: Fresh equigranular intrusive rock with 95% content of plagioclase and as accessory minerals biotite and pyroxene are observed. This rock belongs to the outcrop more mafic of the Andahuaylas – Yauri Batholith, recognized by modal and geochemical analysis as a gabbro

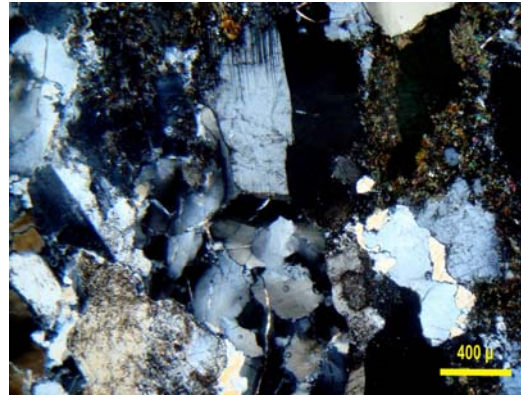
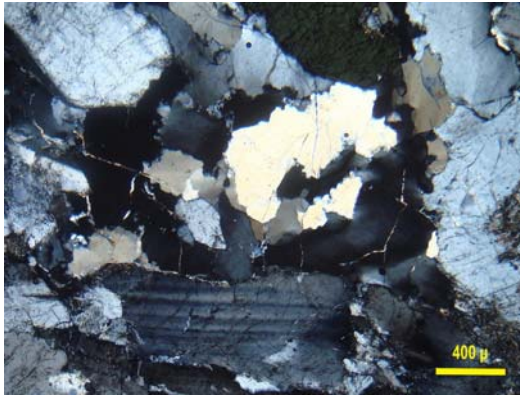


Photo 5.2a y b.- Sample GE24 – 033: Intrusive rock with coarse grain of the Andahuaylas – Yauri Batholith. It can be seen plagioclase and quartz ± biotite and hornblende as the major minerals; it has a weak sericitación of plagioclase. It was interpreted by modal and geochemistry analysis as a quartz diorite.

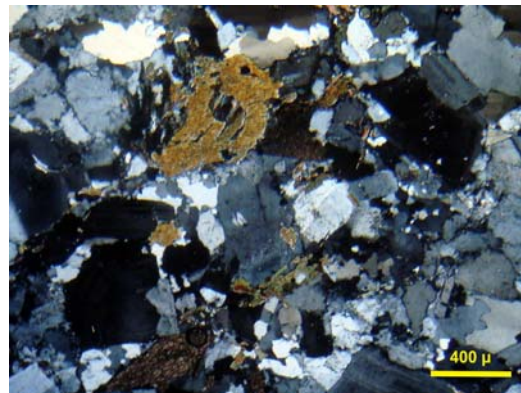
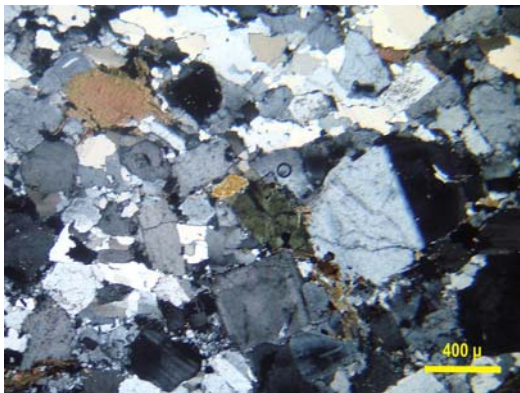


Photo 5.3a y b.- Sample GE24 – 035: Equigranular intrusive rock with medium grain of the Andahuaylas - Yauri Batholith. You can see the content of quartz with respect to previous samples; it was interpreted by modal and geochemistry analysis as a tonalite.

Cotabambas Cluster

On the other hand in the Cotabambas Cluster there are also some mafic intrusive facies as in the case of the samples GE24 - 078 which was described in the field as a rock melanocratic and medium grain equigranular, composed of plagioclase \pm quartz - biotite. This rock could be a host rock of all porphyries known as Cotabambas Cluster. The modal analysis indicates that it would be a quartz diorite. But keep in mind that there have been some millimeter veins of hydrothermal quartz that could be adding silica to geochemical analysis, in any case would be considered between a diorite to quartz diorite.

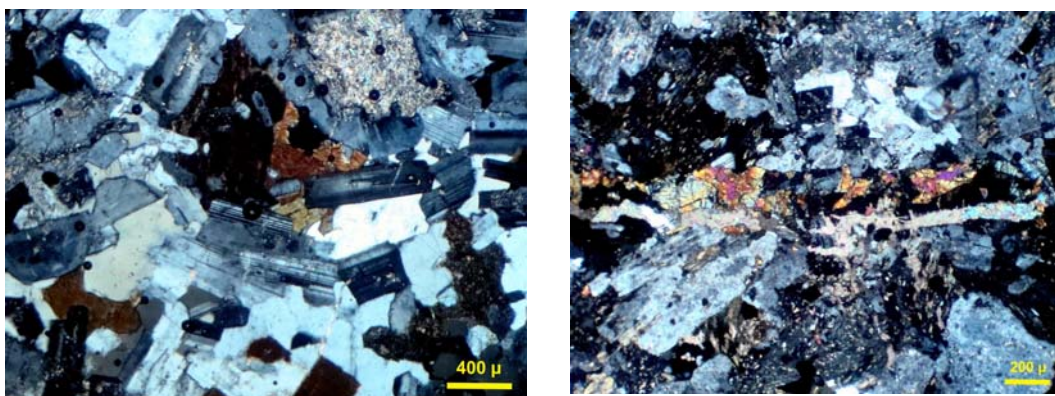


Photo 5.4a y b.- Sample GE24 – 078: Equigranular intrusive rock with medium-grain of Cotabambas Cluster. You can see the presence of quartz intergrown with the plagioclase, as well as the hydrothermal quartz veins with sericite – muscovite halos. The interpretation of modal and geochemical analysis allows classifying this rock as diorite to quartz diorite.

On the other hand the sample GE24 - 064 in TAS graphic for plutonic rocks fall within the granodioritic rocks field, but the interpretation of thin sections indicates that this sample has less than 10% quartz, 50% plagioclase and 40% potassic feldspar (monzonite - monzodiorite), reason why rock is should not fit within the granodiorite field. The basic reason for interpreting that the geochemical analysis is not representative is the moderate hydrothermal alteration seen in the matrix of the intrusive rock (sericitization), this moderate alteration is reflected in the value of LOI (Loss Oxygen Ignition) which is 5.1. For this reason the position of this sample as granodiorite in the TAS diagram is ruled out and would be considered a monzonite to monzodiorite.

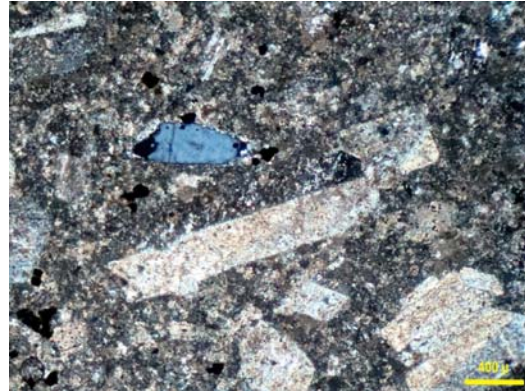
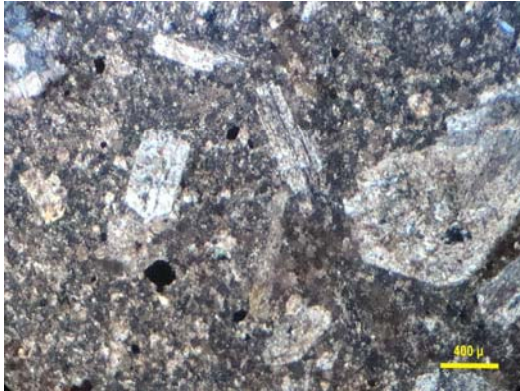


Photo 5.5a y b.- Sample GE24 – 064: Intrusive rock of fine-grain with porphyritic texture. It can be seen moderate sericitization affecting the matrix and some plagioclase and potassium feldspar. The presence of quartz is minimal, modal analysis allowed to classify this rock as a monzonite to monzodiorite.

The sample GE24 - 062A in the TAS graphic of plutonic rocks fall within the field of monzonite rocks and at the field it was described as an leucocratic intrusive rock with porphyritic texture and phenocrysts of hornblende reaching 2 cm. and a matrix composed mainly of plagioclase and possible alkali feldspar with practically no presence of quartz. The interpretations of thin sections allowed defining this rock as a monzonite to monzodiorite. The sample GE24 - 061 has similar textural and mineralogical characteristics of the sample GE24 - 062 so it can be considered also as a monzonite to monzodiorite.

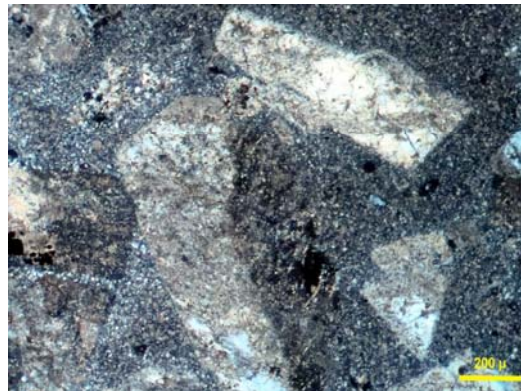
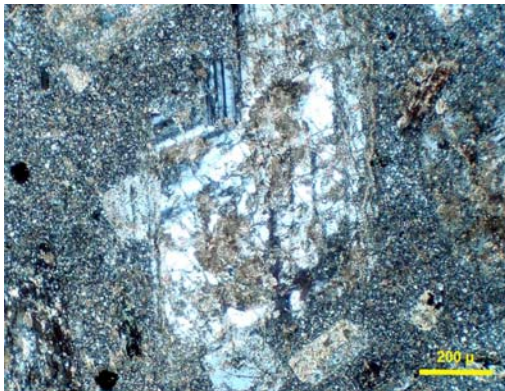


Photo 5.6 a y b.- Sample GE24 – 062: Intrusive rock with porphyritic texture. It can be observed moderate to strong sericitization affecting the matrix and some plagioclase and potassium feldspar. The presence of quartz is minimal, modal analysis allowed to classify this rock as a monzonite to monzodiorite.

By other hand the sample GE24 - 063 was described at the field as an intrusive rock with porphyritic texture and anhedral phenocrysts of feldspar and fine matrix, composed mainly of

plagioclases. The presence of quartz is almost zero, which is interpreted as a rock with monzonite composition, coinciding with the TAS diagram. It can be interpreted that The LOI of this sample is 5.4.

The sample GE24 – 59B was described at field as intrusive rock with fine porphyry texture, The quartz presence in less 5%. It is possible to see feldspar phenocrysts.

Geochemical analysis indicates that this rock falls completely within the monzonite field as previous samples. It is considered a fresh rock, feature that is reflected in its LOI which is less than 2. Petrographic interpretations by the Streckeisen diagram indicate that the intrusive rocks of Cotabambas Cluster have more content of alkali feldspar. The compositional range is between diorites (host rock), monzodiorites, monzonites, coinciding with the interpretations of [Perelló et al., \(2003\)](#) "Although the dominant composition of the unit is dioritic, the local variations in its mineralogy it is interpreted as monzodiorites, quartzdiorites and tonalites". These same rocks interpreted by geochemical analysis fall predominantly within the monzonite, diorite to quartz diorite – granodiorite field (Cox et al., 1979)

Trapiche Project

The sample GE24 - 010 (Photo 5.7a y b) as the geochemical analysis and plotting in the TAS diagram ([Cox et al., 1979](#)) (Fig. 5.4) indicates that the sample falls within the quartz diorite to granodiorite field. Microscopic interpretations made by modal analysis indicate that this rock belongs to the tonalite field (Streckeisen Diagram). The quartz content between a tonalite and a granodiorite is the same; the difference is the potassium feldspar content. The sample GE24 - 010 has less than 10% potassic feldspar content corroborating its tonalitic affinity.

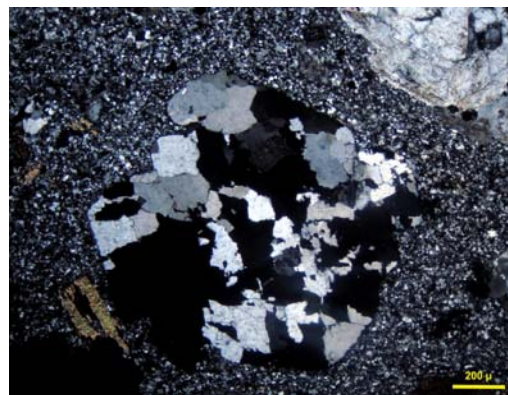
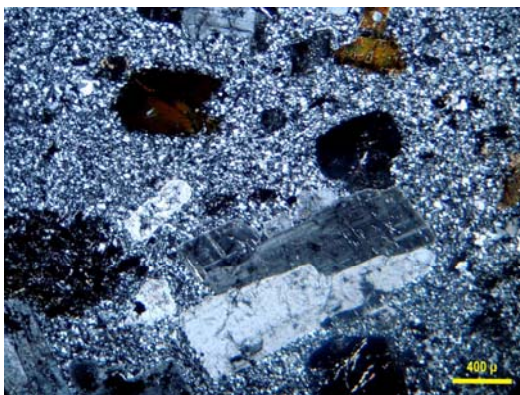


Photo 5.7a y b.- Sample GE24 – 010: Intrusive rock with porphyritic texture, light gray color and plagioclase matrix. You can see also plagioclase phenocrysts within aphanitic matrix, as accessory minerals it has biotite and hornblende. It is also observed quartz content greater than 20% in both aphanitic matrix and as small crystals.

Antilla Project

The sample GE24 - 027 (Photo 5.8a y b) was described at field as a leucocratic intrusive rock with porphyritic texture and phenocrysts of potassium feldspar \pm plagioclase and biotite. The geochemical analysis show the results of major elements in the granodiorite field near the border with monzonite field. The interpretation of thin sections indicates that this is an intrusive rock with less than 5% quartz content, with the presence of potassium feldspar and plagioclase as essential minerals; being classified as a monzonitic rock with porphyritic texture. This small bias can be interpreted to be due to their relatively high LOI value of 4.2.

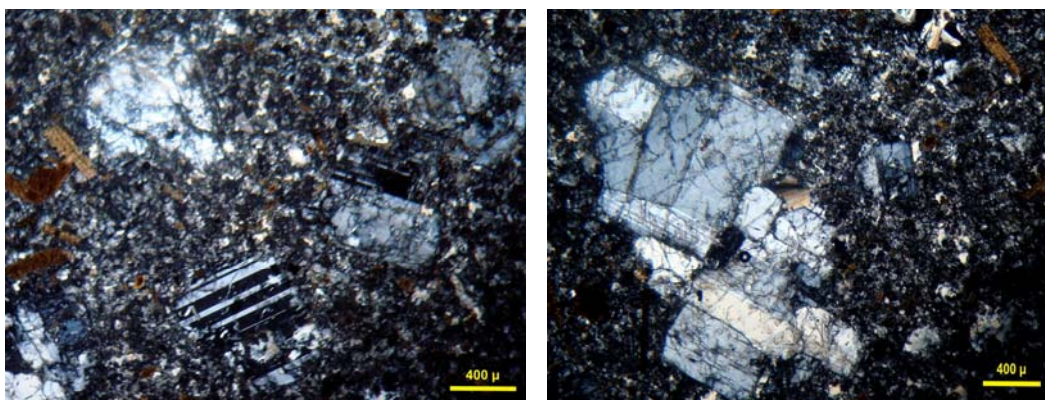


Photo 5.8a y b.- Sample GE24 – 027: Intrusive rock with porphyritic texture. Note also the phenocrysts of plagioclase and potassium feldspar within aphanitic matrix, as accessory minerals it has biotite. The quartz content is almost zero in both aphanitic matrix and as small crystals.

Las Bambas Cluster

Samples GE24 - 083, 084 and 086 formed within the TAS diagram (Cox et al., 1979) (Fig. 5.4) a samples group that are plotted within the monzonite field. The LOI index for each of the samples is small (<2).

Petromineralogy studies using thin sections of the sample GE24 – 083 (Photo 5.9a y b) indicate that this sample has more than 20% quartz content and is classified as a tonalite, by another hand samples GE24 – 084 (Photo 5.10a y b) and 086 have less than 10% quartz and are classified as quartz diorite. Potassium feldspar content is minimal ($<10\%$). It is possible that this geochemistry analysis is adding potassium of ferromagnesian minerals, for example: biotite $K(Mg, Fe)(Al, Fe)Si_3O_{10}(OH, F)_2$.

In summary, the intrusive facies of Las Bambas Cluster are in the range of quartz diorite to tonalite.

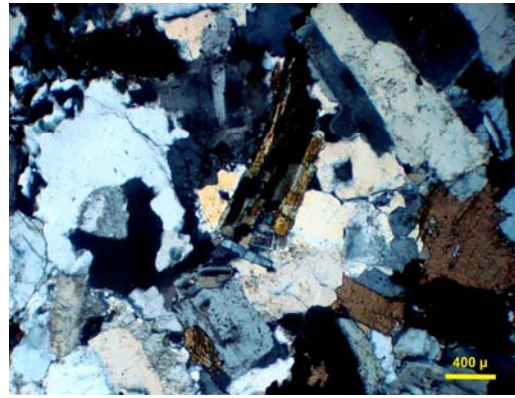
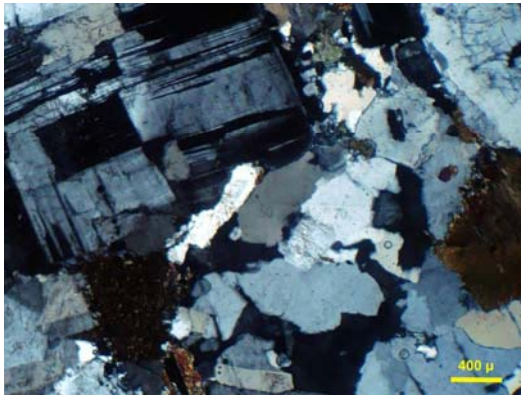


Photo 5.9a y b.- Sample GE24 – 083: Equigranular intrusive rock with coarse grain and approximately 20% quartz and 65% of plagioclase \pm potassium feldspar. Sample classified as a tonalitic rock.

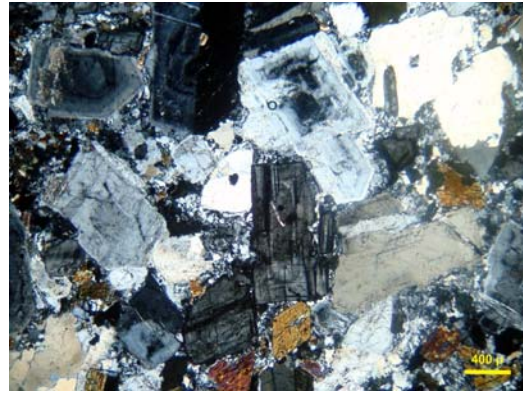
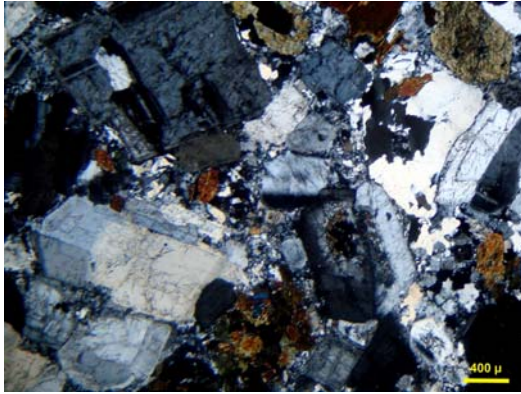


Photo 5.10a y b.- Sample GE24 – 084: Equigranular intrusive rock with coarse grain and less than 5% quartz and composed almost exclusively of plagioclase \pm potassium feldspar. Sample classified as a diorite.

Tintaya Cluster

Samples GE24 - 90A, 102, 106 (Photo 5.11a y b) and 107 shown in TAS Diagram (Fig. 5.4) a wide range of composition from gabbros, monzonites to granodiorites.

The sample GE24 – 90A was described at field as a medium grain intrusive rock, melanocratic, with less than 10% quartz and abundant ferromagnesian minerals (biotite and amphibole), and geochemical and petro mineralogical studies classify this rock as a gabbro.

The sample GE24 - 102 was described at field as an intrusive rock with porphyritic texture (potassium feldspars \pm plagioclases and hornblendes), leucocratic, pink shades are seen in some euhedral feldspars. Weakly altered (LOI: 2.7), with less than 10% quartz. Petro mineralogical and geochemical analyses classify this rock as a monzonite.

The sample GE24 – 106 (Photo 5.11a y b) was described at field as a coarse grain intrusive rock, equigranular, leucocratic, with millimeter crystals of ferromagnesian minerals (biotite and hornblende), geochemical classification describes this rock as a granodiorite, but petro mineralogical studies indicate that there are not more than 20% quartz, being a rock composed almost entirely of a matrix of plagioclase, with less than 10% of potassium feldspar, being considered as a diorite.

The sample GE24 - 107 has the same characteristics as the sample 106 therefore may be considered as a diorite.

Both samples GE24 - 106 and 107 could also be adjacent to the field of monzodiorite rocks.

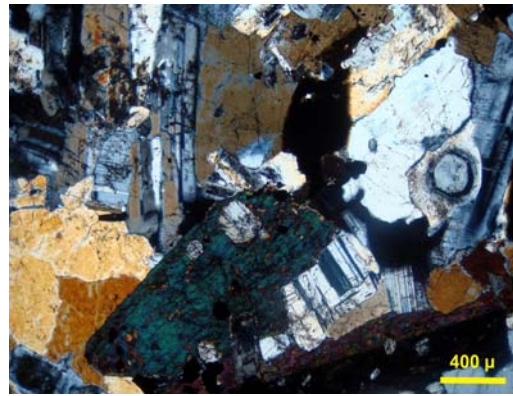
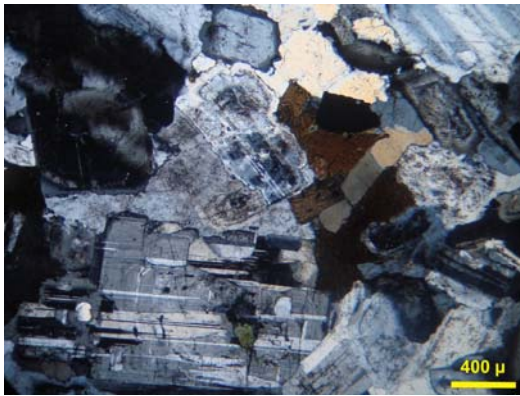


Photo 5.11a y b.- Sample GE24 – 106: Equigranular intrusive rock with coarse grain. Rock composed almost exclusively of plagioclase ± potassium feldspar, with less than 10% quartz. Sample classified as a dioritic rock.

6.- ISOTOPIC AND GEOCRONOLOGY DATA INTERPRETATION IN THE ANDAHUAYLAS - YAURI BATHOLITH"

INTRODUCTION

The metallogenetic belt of the Andahuaylas Yauri batholith is characterized mainly by the occurrence of deposits of type Cu - Mo porphyry and skarn. In smaller measure also there are other mineralization styles like veins and beds associated to several porphyry systems. This belt host important deposits and prospect as Tintaya, The Bambas, Antapacay, Los Chancas, Katanga, Cotabambas, Trapiche, Morosayhuas etc.

The geology is characterized by the occurrence of marine and continental sequences of Mesozoic and Cenozoic age which were intruded for a multiphase igneous system (Andahuaylas - Yauri Batholith) of Eocene - Oligocene age which has evolution mainly from early phases with presence of gabros, gabrodiorites and diorites, followed by intermediate phases with monzodiorites and cuarzodiorites to arrive finally to phases more acids in the mineralización stage with presence of granodiorites and monzonites.

A series of late dikes of varied composition cuts the previous phases indistinctly.

The economic mineralization associated to the deposits of porphyry and skarn type are related to late Eoceno - Oligocene intrusions ([Perello et al., 2003](#)). it is certain that exist a good quantity of geochronology data distributed in the Andahuaylas - Yauri batholith, but there are still areas that not had information of the ages of the different intrusions as well as of the mineral occurrences. This is evidenced overalls in the northwest sector of the batholith

A good quantity of geochronology data of the main intrusions associated to the main deposits exists, as well as of the ages of the respective mineralizations. However the information of Pb - Pb and Sr isotopic data are quite poor. The entirety of analyzed data and interpreted it comes from samples taken among 2007 2008 by A. Bustamante and M. Mamani. Starting from these data a series of diagrams has been elaborated to characterize the possible origin of the mineralization and the relationship that it exists between the ores and the host rock. This information was upgraded and reinterpreted starting from the new data that are come obtaining in the field.

Likewise, INGEMMET inside the mark of the international project with the Geologic Service of South Korea (KIGAM), during the 2010 it developed an isotopic - geochronology investigation project in the Batolito Andahuaylas - Yauri batholith, highlight the Cotabambas cluster.

The main objective of this investigation is to know the temporary relationship among the porphyries that conform the Cotabambas cluster by means of Ar-Ar datation and also to determine its mineralization source by means of Pb - Pb and Rb - Sr radiogenic isotopes. Then this information will serve like base to know the possible potential of some other prospects take the premise: "If isotopic signature of well - know deposits is registered and this it is similar with that of some prospects that is inside the same geologic environment, this last has a great potential, due that maybe the mineralization processes have been the same".

Isotopic database of the study area is scarce and it includes 06 samples of Pb - Pb isotopes and 02 samples of Rb/Sr taken 2008 for Bustamante, A. and 02 samples of sulfides taken by Mamani, M.

The information of ages of the different phases of the Andahuaylas - Yauri Batholith has been analyzed from published data in the database of INGEMMET. This information includes a total of 60 samples inside the study area.

To this information sum a new database from the international cooperation among INGEMMET and KIGAM that it includes 2 datation Ar-Ar, 4 datation Rb-Sr and 4 Pb - Pb isotopes. This investigation was carried out exclusively in the Cotabambas cluster that involves the Azullccaca, Huacile, Ccalla and Ccarayoc porphyry deposits.

6.1 Interpretation of isotope data

Cotabambas Cluster

During 2010 KIGAM and INGEMMET realized evaluation studies of economic potential of the Andahuaylas – Yauri Batholith. During the first field trip (March), some samples were collected for isotopic studies of the main porphyry centers of Cotabambas cluster (Tabla 6.1). The sampling methodology for Pb-Pb isotope studies was to identify in the core drilling the areas of potassic alteration of the main possible porphyry or mineralizing and sequentially identify all the different types of characteristics veins of the porphyry with areas of highest law of Cu - Au. The veins of most interest to this isotopic study were the type B veins (veins of quartz with a central suture of sulphides) within which the separate mineral for the four porphyry centers was pyrite.

he geological description of the type B veins in the porphyry of this cluster would be summarized as centimetric quartz veins, irregular, with a central suture filled by pyrite

and chalcopyrite within a zone of potassic alteration, note the average pink color rock surrounding the veins (potassium feldspar).

The separation of minerals was done manually at the INGEMMET, using a binocular microscope Olympus model. The samples were labeled and sent to the Geological Survey of South Korea (KIGAM) for their isotopic analysis.

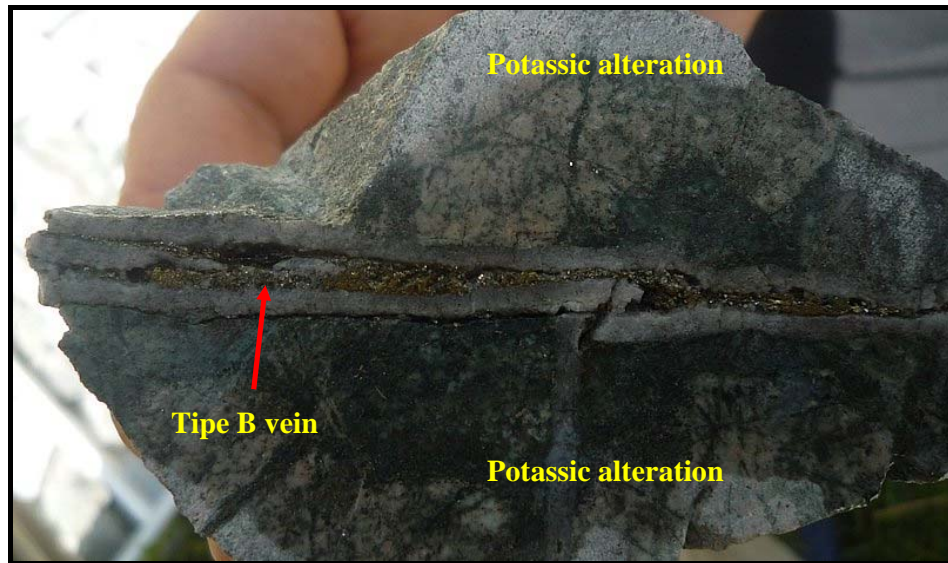


Photo N° 6.1.- B vein Type, with a central suture of sulfides (pyrite and chalcopyrite, notice the potassic alteration.

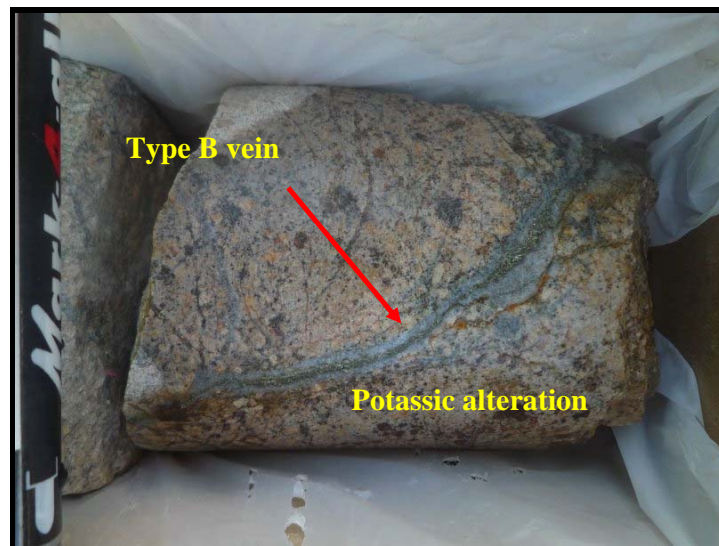


Photo N° 6.2.- Type B vein within the potassic alteration (Cotabambas cluster)

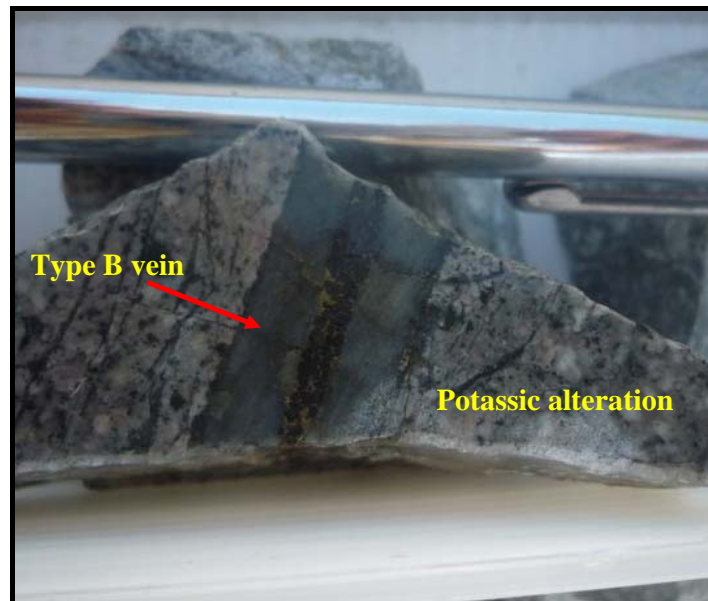


Photo N° 6.3.- Type B vein within potassic alteration, notice the central suture of pyrite and chalcopyrite (Cotabambas cluster)

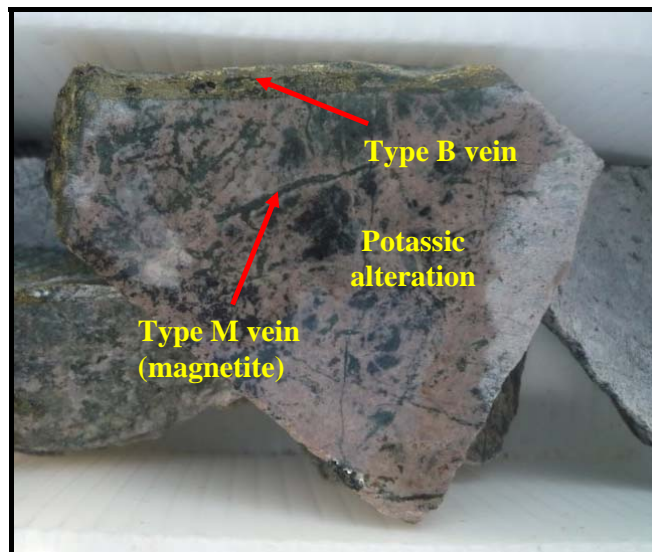


Photo N° 6.4.- Type B and M veins with potassic alteration of the main porphyry



Foto N° 6.5.- Porphyritic texture of the fresh rock of the Cotabambas cluster.

Ar-Ar geochronological studies had a very similar methodology. It identified the "*main porphyry*" within each ones porphyries of Cotabambas cluster. The studies focused on the potassic alteration, trying to identify the type EB veins (early biotite), with the purpose of dating the hydrothermal biotite, a product of hydrothermal alteration of the *main porphyry*.

The EB type veins were almost absent from drill cores and if present were millimeter very difficult to separate for geochronological studies. In this way only could separate the biotite of the Ccalla and Azullccaca porphyries. Biotites were forming small grains and were related to potassic alteration where the main veins were type "B" and "M".

These biotites were separated manually at the INGEMMET laboratories using a binocular microscope, and then be labeled and sent to the Geological Survey of Korea (KIGAM) for geochronological studies.

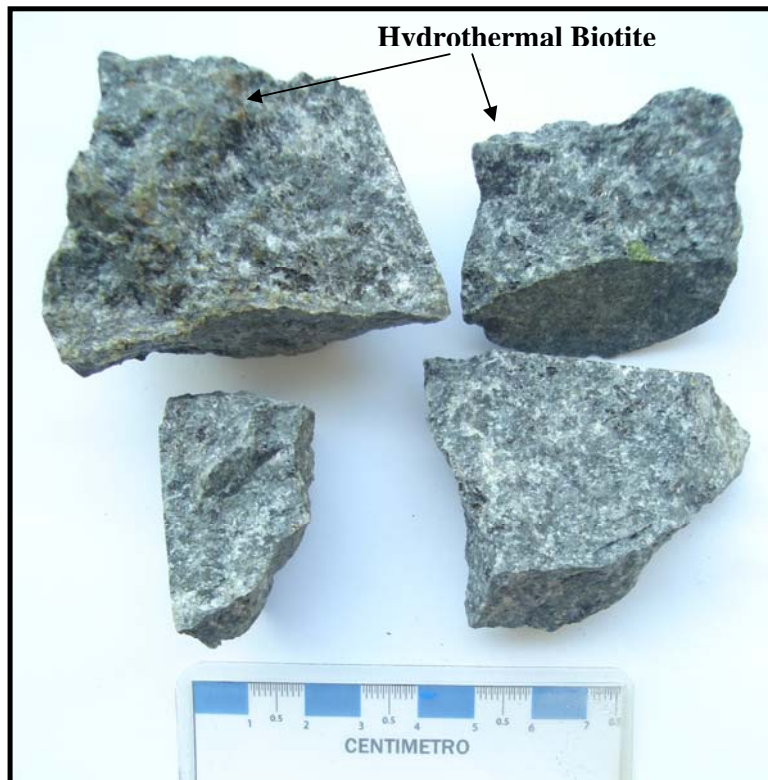


Foto N° 6.6.- Hydrothermal biotite in small grains associated with potassic alteration and type B veins (Azulccaca Porphyry).

Isotopic studies of Rb-Sr, followed a similar methodology of the geochronological studies mentioned above. Hydrothermal alterations were identified in the cores, but this time we focus on phyllic alteration (quartz - sericite). The objective of this sampling was to identify the sericite and chlorite, in order to obtain a sample rich in sericite and other poor in sericite, in order to correct the excess of the first sample and be able to realize isotopic studies.

Phyllic alteration was not very good development. It was decided not to try to separate crystals of sericite (model age), but work through total rock (isochronous age). We collected a total of 8 samples, two samples per each porphyritic deposit, a sample rich and another poor of sericite, in order to obtain a corrected line of the isotope interpretations.

Las muestras fueron además evaluadas mediante el PIMA, el cual descartó algunas muestras erróneas, donde se había confundido la clorita con la illita, la cual es muy similar pero de aspecto más jabonoso.

The samples were also evaluated using the PIMA, which ruled out some wrong samples, which had confused the chlorite to illite, which is very similar but soapy looking.

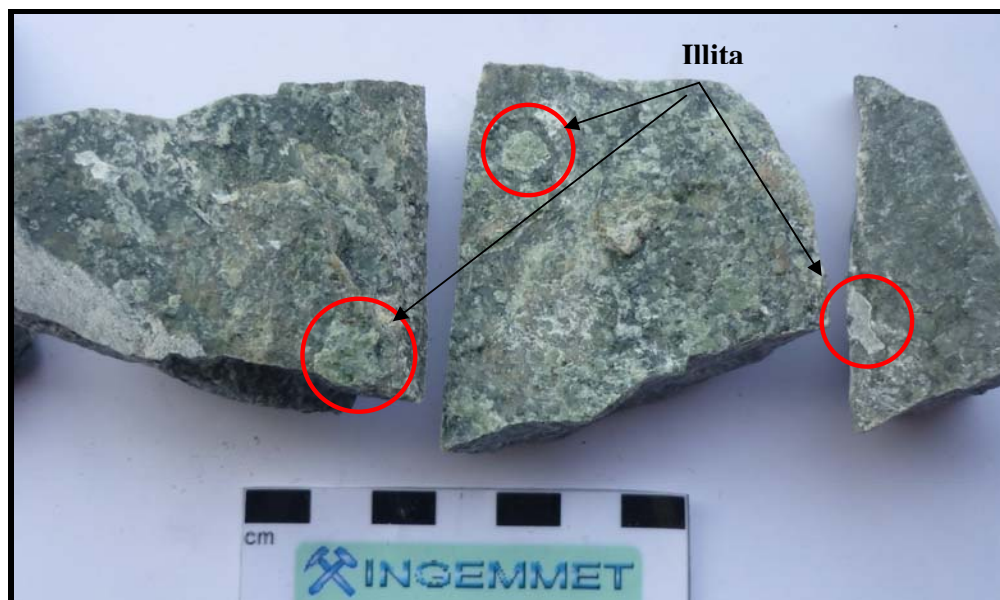


Photo N° 6.7.- Disregarded sample for isotopic studies where it is observed illite minerals, who had been confused by the chlorite. (Ccarayoc Porphyry).



Photo N° 6.8.- Samples with chlorite (Azullccaca Porphyry)



Photo N° 6.9.- Sericite (Huacile Porphyry)

Table 6.1 Samples list for isotopic and geochronology studies in the Cotabambas cluster.

ISOTOPIC STUDY IN PROYECT INGEMMET - KIGAM

IDEM	SAMPLE	DEPOSIT	Cluster	MINERAL STUDY	METHOD		Observation
1	Kigam-2010-020	Ccalla Porphyry (Au - Cu)	Cotabambas	Biotite	Ar - Ar	Geochronology	separated sample
2	Kigam-2010-010	Azullocaca Porphyry (Au-Cu)	Cotabambas	Biotite	Ar - Ar	Geochronology	separated sample
3	Kigam-2010-011	Azullocaca Porphyry (Au-Cu)	Cotabambas	Clorite	Rb-Sr	Geochronology	whole rock
4	Kigam-2010-012	Azullocaca Porphyry (Au-Cu)	Cotabambas	Sericite	Rb-Sr	Geochronology	whole rock
5	Kigam-2010-016	Ccalla Porphyry (Au-Cu)	Cotabambas	Clorite	Rb-Sr	Geochronology	whole rock
6	Kigam-2010-017	Ccalla Porphyry (Au-Cu)	Cotabambas	Sericite	Rb-Sr	Geochronology	whole rock
7	Kigam-2010-003	Huadlle Porphyry (Au-Cu)	Cotabambas	Clorite	Rb-Sr	Geochronology	whole rock
8	Kigam-2010-002	Huadlle Porphyry (Au-Cu)	Cotabambas	Sericite	Rb-Sr	Geochronology	whole rock
9	Kigam-2010-008	Ccarayoc Porphyry (Au-Cu)	Cotabambas	Clorite	Rb-Sr	Geochronology	whole rock
10	Kigam-2010-007	Ccarayoc Porphyry (Au-Cu)	Cotabambas	Sericite	Rb-Sr	Geochronology	whole rock
11	Kigam-2010-023	Ccalla Porphyry (Au - Cu)	Cotabambas	Pyrite	Pb-Pb	Isotopic Geochemistry	separated sample
12	Kigam-2010-004	Huadlle Porphyry (Au - Cu)	Cotabambas	Pyrite	Pb-Pb	Isotopic Geochemistry	separated sample
13	Kigam-2010-013	Azullocaca Porphyry (Au-Cu)	Cotabambas	Pyrite	Pb-Pb	Isotopic Geochemistry	separated sample
14	Kigam-2010-005	Ccarayoc Porphyry (Au-Cu)	Cotabambas	Pyrite	Pb-Pb	Isotopic Geochemistry	*no separated sample

*the Kigam-2010-005 it is impossible to separate because the mineralización is very fine, but is possible separate for dense fluids and can to be study for pyrite o calcopyrite.

04-May-10

The interpretation of isotope data was made from 10 samples divided into 08 samples from ore sulphide (pyrite and galena) and 02 samples belonging to the host rock (Table 6.2).

Table 6.2 Pb isotopic results of NW Andahuaylas-Yauri Batholith

Samples	LONG	LAT	Material	$^{206}\text{Pb}/^{204}\text{Pb}$	Error %	$^{207}\text{Pb}/^{204}\text{Pb}$	Error %	$^{208}\text{Pb}/^{204}\text{Pb}$	Error %	Author
UTU-001	-72.816	-14.352	Pirita	18.596	0.041	15.629	0.044	38.661	0.044	Bustamante., 2008
UTU-002	-72.802	-14.349	Pirita	18.645	0.007	15.652	0.010	38.760	0.010	Bustamante., 2008
UTU-003	-72.815	-14.354	Pirita	18.641	0.020	15.654	0.019	38.732	0.023	Bustamante., 2008
UTU-004	-72.815	-14.349	Pirita	18.675	1.055	15.729	1.061	38.963	1.065	Bustamante., 2008
UTU-005	-72.815	-14.354	Pirita	18.703	0.009	15.662	0.009	38.790	0.009	Bustamante., 2008
UTU-013	-72.833	-14.366	Pirita	18.492	0.007	15.633	0.006	38.595	0.007	Bustamante., 2008
UTU-012	-72.815	-14.349	Diorita	18.848	0.008	15.649	0.008	38.941	0.008	Bustamante., 2008
UTU-016	-72.815	-14.351	Diorita	18.755	0.007	15.638	0.008	38.839	0.008	Bustamante., 2008
CH-4	-72.660	-14.181	galena	18.915	-	15.665	-	38.632	-	Mamani et al., 2008
LG-16	-72.660	-14.181	galena	18.724	-	15.647	-	-	-	Mamani et al., 2009

As mentioned the Pb isotopic data of the study area is still quite poor however has made a preliminary interpretation of the samples of ore (sulphide) and host rock with existing data of the samples located in the NW sector of the belt. To characterize the possible sources of metals has been worked using Plumbotectónico and Toriogenico diagrams.

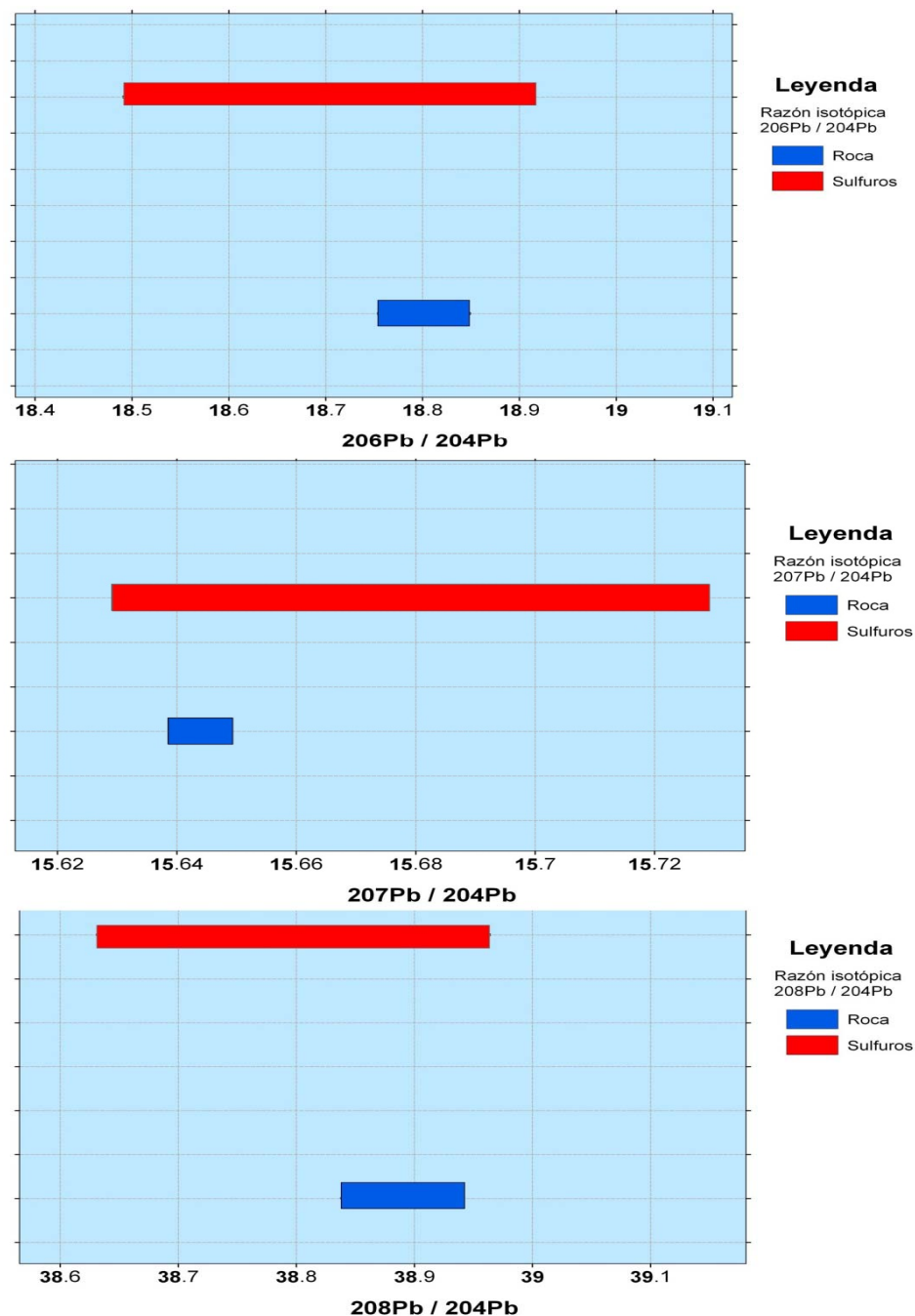


Figure 6.1: Comparison of ranges of isotopic ratios of $^{206}\text{Pb}/^{204}\text{Pb}$, $^{207}\text{Pb}/^{204}\text{Pb}$ and $^{208}\text{Pb}/^{204}\text{Pb}$ of mineralization and host rock.

In Figure 6.1 may provide that in general the values of the isotopic ratios of $^{206}\text{Pb}/^{204}\text{Pb}$ are somewhat greater in the host rock (diorite) than in the samples of ore (sulphide). This is because in general the rocks (diorite) store more uranium in their composition than the sulphides, in this case pyrite and galena.

Then the isotopic values of the rocks are more radiogenic than the values of the ore due to show the evolution of uranium from the time of its formation until today. The opposite occurs with ore samples showing the initial isotopic composition of lead and that the sulfides generally do not have uranium within its crystal lattice.

The sulfides show a wide variation and even more radiogenic than the host rock with respect to the isotopic ratios of $^{208}\text{Pb}/^{204}\text{Pb}$ and $^{207}\text{Pb}/^{204}\text{Pb}$. This variation would indicate that fluids had contamination crustal subordinate of oldest rocks (greater enrichment relative to ^{207}Pb to ^{206}Pb) and probably with reason Th / Pb than the average upper crust.

Analysis of the diagrams $^{207}\text{Pb}/^{204}\text{Pb}$ vs $^{206}\text{Pb}/^{204}\text{Pb}$ and $^{208}\text{Pb}/^{204}\text{Pb}$ vs $^{206}\text{Pb}/^{204}\text{Pb}$

In the diagram $^{207}\text{Pb}/^{204}\text{Pb}$ vs $^{206}\text{Pb}/^{204}\text{Pb}$ established for Uranogénico Plumbotectónico model (Figure 6.2) we can see that most mineralized samples (pyrite and galena) and host rocks (diorite) are located between the curve of upper crust and orogenic mixture curve which suggests that the main source of metals are upper crustal rocks. As the most sulphides points follow the same trend of Pb isotopic evolution curve of the host intrusive rocks, may be admitted to these rocks as the Pb main source of the ore minerals. In the diagram $^{208}\text{Pb}/^{204}\text{Pb}$ vs $^{206}\text{Pb}/^{204}\text{Pb}$ established for the Toriogénico model (Figure 6.3) you can see that the source has a ratio Th / Pb above average but did not become elevated. Apparently the lead is not from mantle because if so the values would be below the orogen curve. Most samples of ore show isotope compositions of $^{208}\text{Pb}/^{204}\text{Pb}$, $^{207}\text{Pb}/^{204}\text{Pb}$ y $^{206}\text{Pb}/^{204}\text{Pb}$ homogeneous suggesting that the main source of metals mineralization would be intrusive complexes themselves and this would result from a fluid flow within the host rocks.

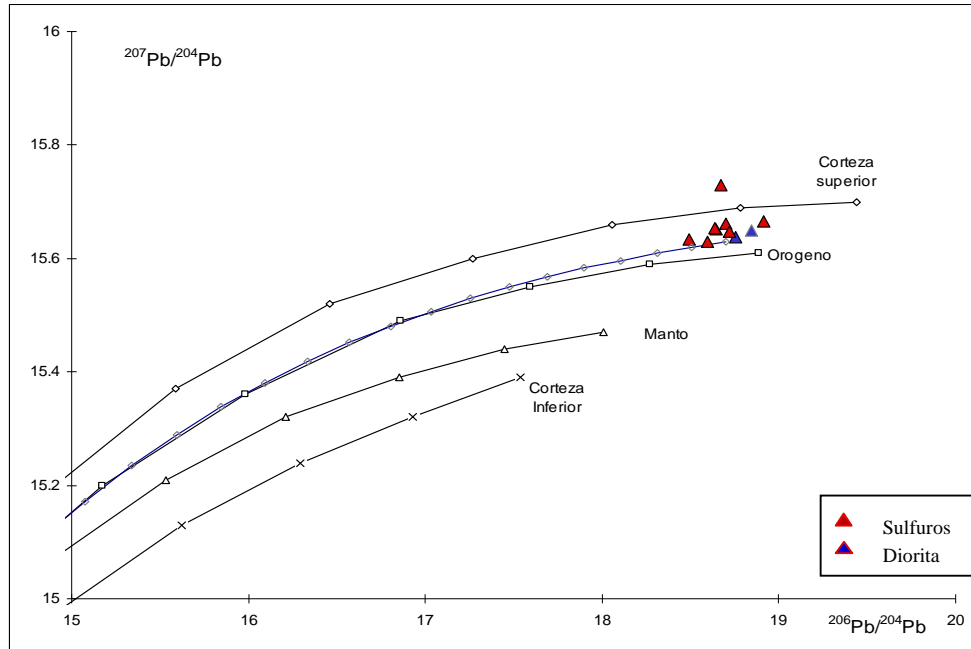


Figure 6.2: Isotope compositions diagram of $^{207}\text{Pb}/^{204}\text{Pb}$ vs $^{206}\text{Pb}/^{204}\text{Pb}$ for samples of ore and fresh rock at NW area of Andahuaylas-Yauri Batholith. It was used as reference curves of Pb isotopic evolution established for the Plumbotectónico-Uranogénico model of Zartman & Doe (1981).

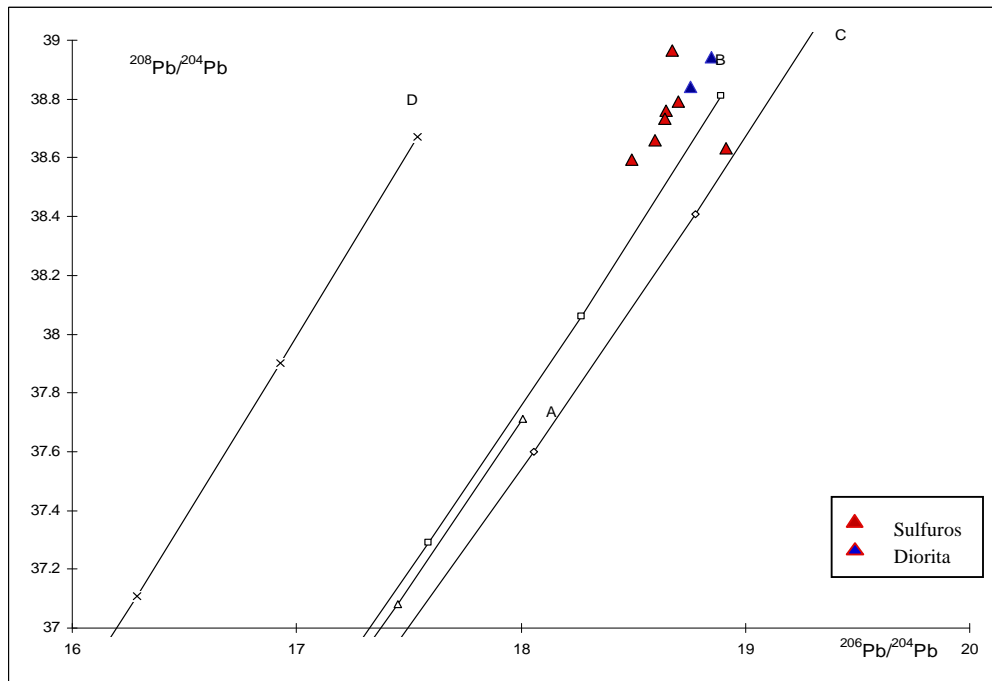


Figure 6.3: Isotope compositions Diagram of $^{208}\text{Pb}/^{204}\text{Pb}$ vs $^{206}\text{Pb}/^{204}\text{Pb}$ for samples of ore and fresh rock at NW area of Andahuaylas-Yauri Batholith. It was used as reference curves of Pb isotopic evolution established for Plumbotectónico-Toriogénico model of Zartman & Doe (1981).

6.2 Location of the study area within the Pb isotopic provinces in the Andes

(Macferlane et al., 1990)

The isotopic values of lead (isotopic signatures) of the rocks and their ore located along the Andes of South America vary in direct proportion to their distance to the Peru-Chile Trench. The Peru-Chile Trench marks the geological boundary between the Nazca Plate to the west to form the south-eastern ocean floor of Pacific Ocean and the South American plate to the east. As is known the convergence of these two plates produces a subduction of the Nazca plate (with sediment cover) in the South American continent generating the fusion of mantle beneath the western edge of South America. Magmas resulting from this fusion emerge producing an interaction with the continental crust; this interaction is manifested in a long history of volcanic activity and generation of associated mineral deposits. Ore formation by subduction along the Peru-Chile Trench has produced significant variations in lead isotope ratios for the different andean deposits. Lead isotopic ratios vary with the distance to the fossa but also vary because of differences in the geology of the South American crust. In general, these isotopic variations reflect the growth of Pb radiogenic in the South American continental crust with respect to the distance to the Peru-Chile Fossa (Macferlane et al., 2005).

The Andes are divided into three fundamental isotope provinces of lead (Macferlane et al., 1990) in these you can see the existence of a parallel to the Peru-Chile Fossa (Fig. 6.4). The isotopic signatures vary from west to east, from the isotopic I province to the isotopic III province, according to its distance to the fossa.

In the isotope compositions diagram of $^{207}\text{Pb}/^{204}\text{Pb}$ vs $^{206}\text{Pb}/^{204}\text{Pb}$ (Figure 6.4) we can see that both samples of ore (pyrite and galena) and the rocks of the study area are mostly located close to the zone of Province II confirming its geographic location within of this province as shown on the map. In the Uranogénico diagram (Fig. 6.4) samples away somewhat from the zone of Province II should however consider that these boundaries between provinces are not rigid and there may be an overlap between them (Macfarlane et al., 2005).

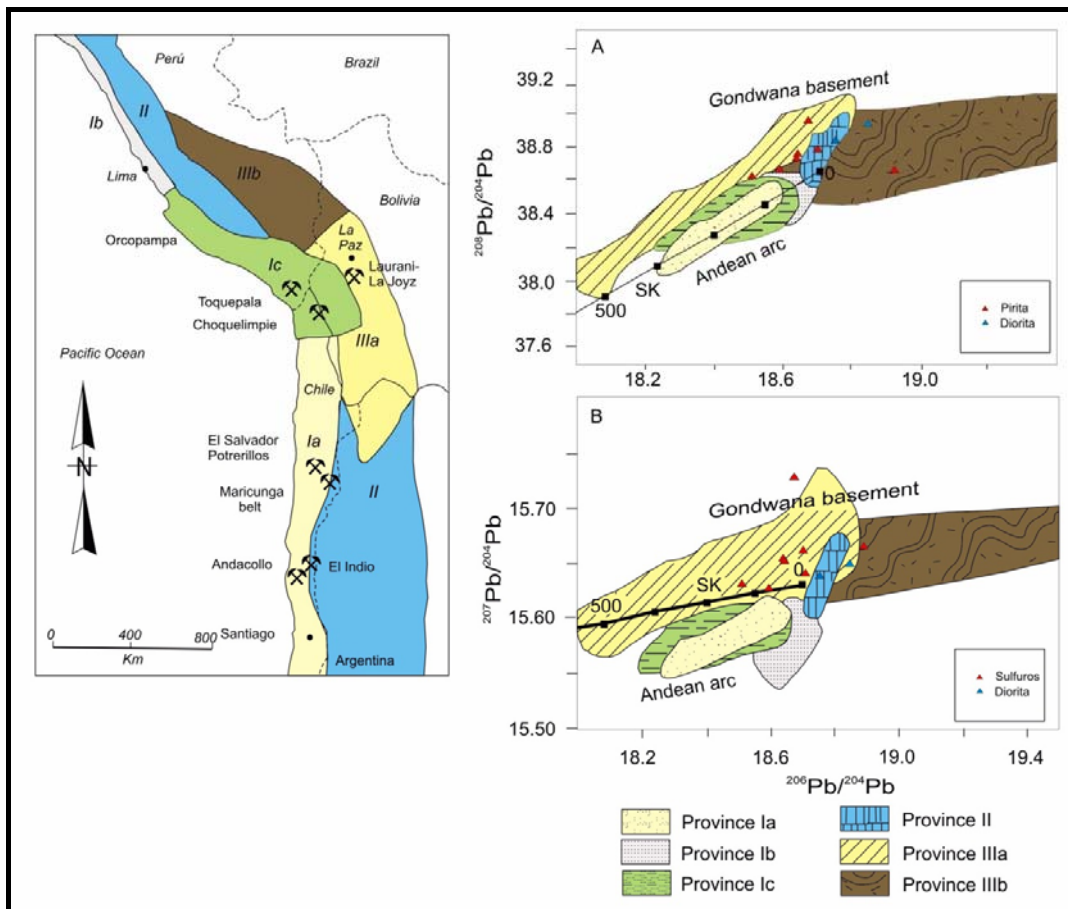


Figure 6.4: Map Pb isotopic provinces of the Central Andes and Thorogénicos diagrams (A) and Uranogénico (B) containing samples of ore and rock in the NW sector of the Andahuaylas – Yauri Batholith (Modified from Macfarlane et al., 1990 by Tosdal et al., 1999).

6.3 Comparisons of Pb isotopic compositions of some deposits in Peru.

For comparative purposes have been plotting the values of Pb isotopic ratios of some typical Peruvian deposits trying to include the main mineralized belts of Peru (Figure 6.5). It can see that there is a lead radiogenic evolution with values of isotopic composition that increase from deposits near the subduction zone to the farthest. Paleocene porphyry deposits in southern Peru (Toquepala and Cerro Verde) have Pb isotopic compositions less radiogenic and San Vicente Mississippi Valley deposit the more radiogenic values. This feature is typical of these deposits because occurs a movement of fluids through sedimentary rocks, but this may also suggest that there is an increase in these isotopic ratios with respect to the distance to the Peru-Chile Trench (Macfarlane et al., 2005). Orcopampa samples demonstrate isotopic ratios with values close to those of the Andahuaylas – Yauri Batholith. Yanacocha and Julcani show outliers with a mayor range

of isotopic composition characteristic of epithermal deposits. Miocene porphyries in northern Peru (Galeno and Michiquillay) have values somewhat higher than the ores of the Andahuaylas - Yauri Batholith but overall seem to express predominantly orogenic material.

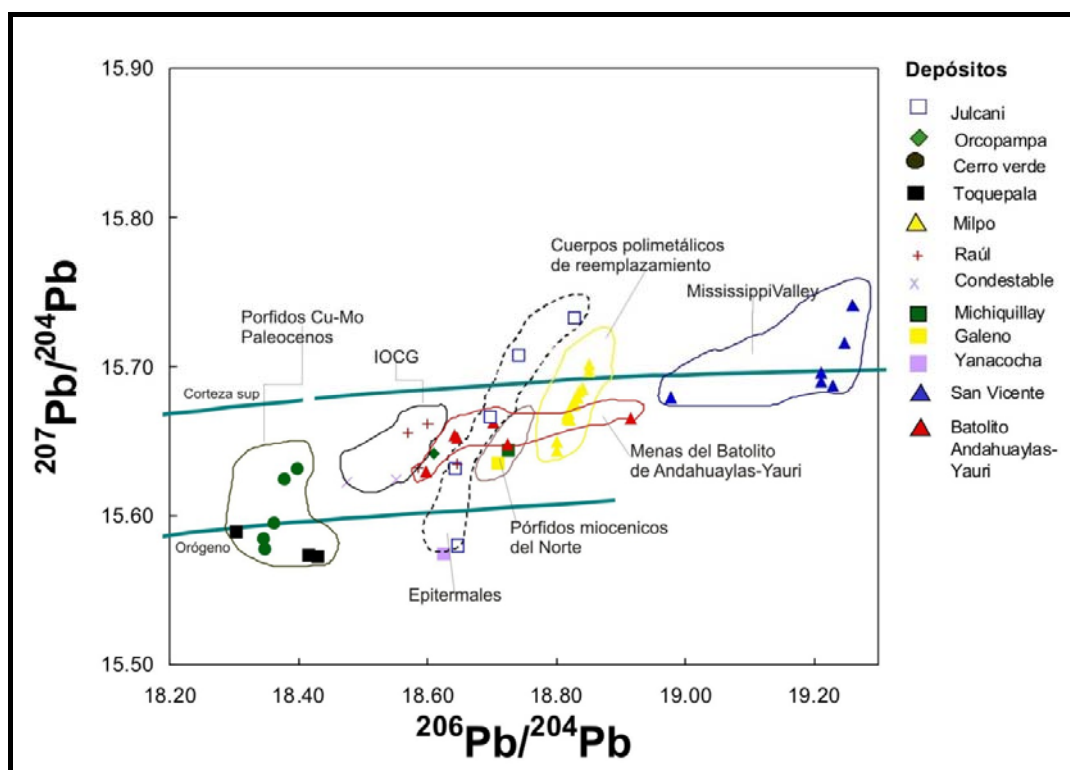


Figure 6.5: Comparison of Pb isotopic ratios of some samples of ore from Andahuaylas - Yauri Batholith with other peruvian deposits. $^{207}\text{Pb}/^{204}\text{Pb}$ vs $^{206}\text{Pb}/^{204}\text{Pb}$ diagram showing Pb isotopic comparison of different deposits.

6.4 Interpretation of Sr Isotopes

To perform a preliminary characterization of metal sources in mineralization was analyzed two samples taken at the Utupara prospect in 2008. The rocks were taken considering the hydrothermal alteration of the main phase of Utupara porphyritic complex, so that the results should refer to the initial isotopic composition of the mineralizing fluid resulting from the interaction with the host rock (see Table 6.3).

Table 6.3: Results about $^{87}\text{Rb}/^{86}\text{Sr}$ and $^{87}\text{Sr}/^{86}\text{Sr}$ relation in the NW sector of the Andahuaylas-Yauri Batholith (Utupara prospect).

No. Campo	Material	Rb(ppm)	Sr(ppm)	$\text{Rb}^{87}/\text{Sr}^{86}$ (X)	Error	$\text{Sr}^{87}/\text{Sr}^{86}$ (Y)	Error
UTU-007 D84	Diorite	57.3	332.4	0.499	0.014	0.706526	0.000056
UTU-008 D84	Diorite	164.43	1116.29	0.4262	0.0034	0.70585	0.00005

The strontium isotopes are used as an indicator of the potential size of porphyry deposits (Tassinari, 2007). If we assume that in general all porphyries are formed by the same process with a variation of the energy of the fluid can then be deduced that those fluids that have a high energy, a strong heat source, used a relatively short time during the ascent process to through the crust indicating they will not have significant crustal contamination and hydrothermal circulation will be in a much larger area. This is manifested by low values in the initial ratio of $\text{Sr}^{87}/\text{Sr}^{86}$ (> 0.706). If the fluids have a low energy these go through the crust in a longer period to have enough time to suffer a crustal contamination which is manifested in high values of the initial ratio of $\text{Sr}^{87}/\text{Sr}^{86}$ (< 0.706) (Tassinari, 2007).

From these relations we can deduce that if the porphyry have low initial Sr isotope ratio then has a chance to be a large deposit, if the ratio is high, indicating strong crustal contamination, then there is likely to be small.

The initial strontium isotope ratios for Utupara (0.7065 to 0.7058) are very similar to those of C° Romero porphyry (0.7063) and Copaquire (0.7058) respectively. For this reason allow to interpret (Figure 6.6) that Utupara prospect has a potential to be a small to medium porphyritic deposit.

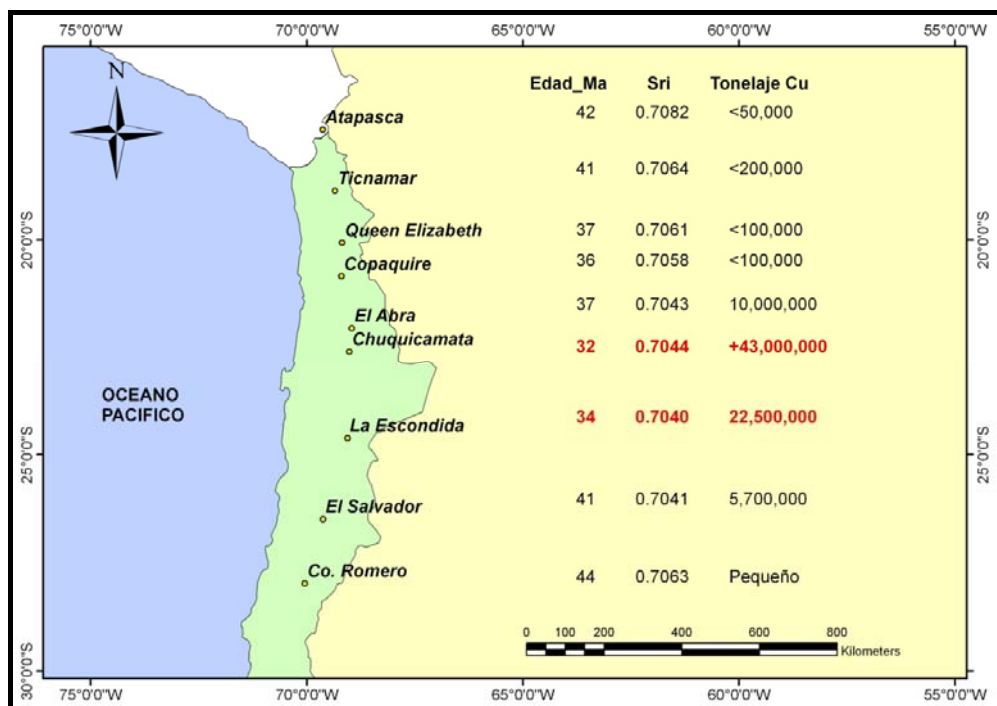


Figure 6.6: Comparison of age, initial isotopic ratios of Sr87/Sr86 and tonnages of different Porphyry deposits of Chile. (Courtesy of F. Munizaga in Tassinari, 2006)

7.- Metallogenic implications and their relationship mining exploration

The Andahuaylas - Yauri Batholith has shown with the passing of the last years of exploration works an increase interest in its mining potential and is important to emphasize that this fact is directly related to the knowledge and understanding of the mineral deposits lie in this area. Doing some of history The Andahuaylas - Yauri Batholith was first recognized as an area with high potential for Fe - Cu hosted in Skarn type deposits (Perelló et al., 2003), but then the understanding of magmatic - hydrothermal systems quickly emerged as an area with high potential for porphyry systems where skarn would be part of a whole series of hidden mineral deposits at different levels of the crust

The study area and therefore its mining potential are directly correlated with the spatial distribution of Andahuaylas - Yauri Batholith (300 x 130 km). This massive intrusive body was emplaced apparently in two stages (Perelló et al., 2003). The first phase with mafic features (gabbros, diorites) and the second phase a little more differentiated (tonalites, granodiorites and monzonites). From the point of view geo-economics the second phase is the exploratory interest and is related with most of the deposits.

The potential of the area is associated with porphyry deposits with different styles of mineralization Cu - Au and Cu - Mo, polymetallic veins (Pb, Zn, Ag), Au Vein, skarn (Cu - Fe), Fe mantles, Red beds with Cu content. If you group all these deposits mentioned above we realize that all are part of the porphyry system model recently updated by Sillitoe (2010), therefore we try to explain the metallogeny of Andahuaylas - Yauri Batholith from this updated perspective.

The structural control of Andahuaylas - Yauri Batholith has dominant features of compressional stress, which could had lifted structural blocks causing different levels of erosion and depth and therefore exposing the different types of mineral deposits related to porphyry systems. Field evidence indicates that these normal or reverse faults were related to strike movements (strike slip fault), which may be due to a much larger scheme associated with oblique convergence of tectonic plates, which may have had its greater expression in the structural high Cusco - Puno or also known as USA (Urcos - Sichuan - Ayaviri) (Gilder et al., 2003). Compressional regime would have been an effort conducive to the emplacement of the intrusive bodies and the generation of different porphyry systems in an environment very similar to a structural jog to crustal-scale.

Assuming that the porphyry system belong a second magmatic pulse and were emplaced in the same or similar geological conditions (depth) we can say that the eastern part of the Andahuaylas - Yauri Batholith have a higher level of erosion because there are more porphyry and skarn deposits at a shallow level, while the western part outcrop a greater number of veins with a few exceptions of porphyry deposits such as Trapiche and Utupara. (see Fig xx)

Clear evidence of the strong level of erosion that affected the Andahuaylas – Yauri Batholith, is expressed in the red beds with anomalous values of Cu that outcrop in the eastern boundary of Andahuaylas – Yauri Batholith (Losa, 2004). Apparently the red beds are the product of erosion of porphyry deposits that outcrop in this sector, creating an entire sedimentary sequence (San Jerónimo Group) with anomalous concentrations of Cu, but nowadays they don have a strong implication in the Cu production in Peru and are usually exploited handmade by informal miners.

Filed Interpretations have allowed us to observe the same geological process in the northern part of the Andahuaylas – Yauri Batholith, but this time associated with the Fm. Muñani. While Cu concentrations are lower on the eastern side, the importance is that these low concentrations of Cu indicate that the level of erosion of porphyry deposits was not the same throughout the Andahuaylas – Yauri Batholith.

Another important observation is that Muñani formation has been dated as before the second magmatic pulse of Batholith Andahuaylas - Yauri, which also indicate that the first pulse may have caused some porphyry systems, perhaps now eroded or still undiscovered. Field observations can appreciate that the mineralization (chalcopyrite, pyrite, and hematite) in the red beds of the Muñani formation is related to millimeter parallel laminations to bedding. Subvolcanic dikes cut the sedimentary sequence and remove the mineralization of sedimentary rocks creating halos of Cu (malachite) around the dikes that are worked handmade.

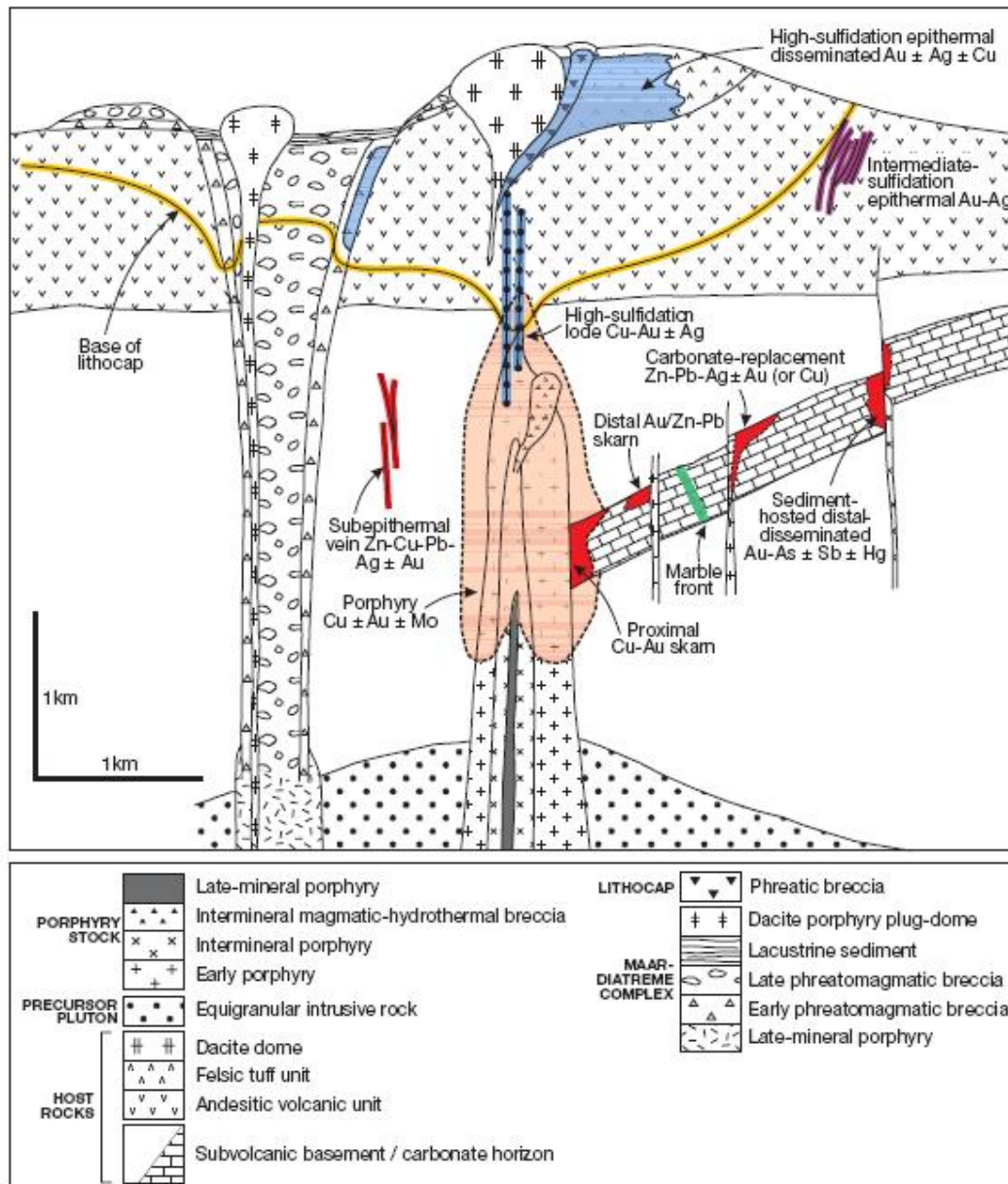


Fig. 7.1. Scheme of a Cu porphyry system that shows its spatial relationship with the host rock and its possible spatial relationship with the different types of deposits (high - moderate and low sulphidation epithermal, skarn, replacement bodies and disseminated deposits in sedimentary rocks) (Sillitoe, 2010).

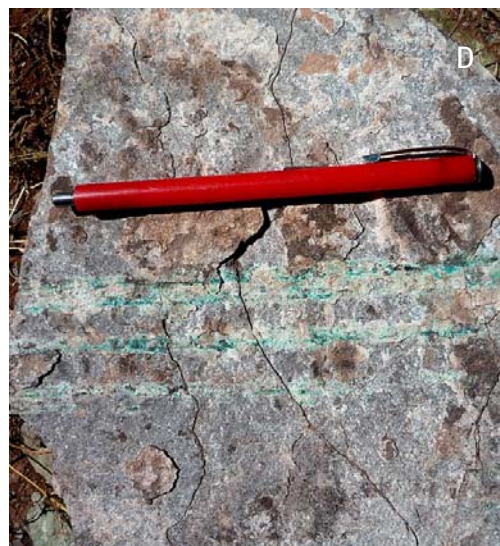
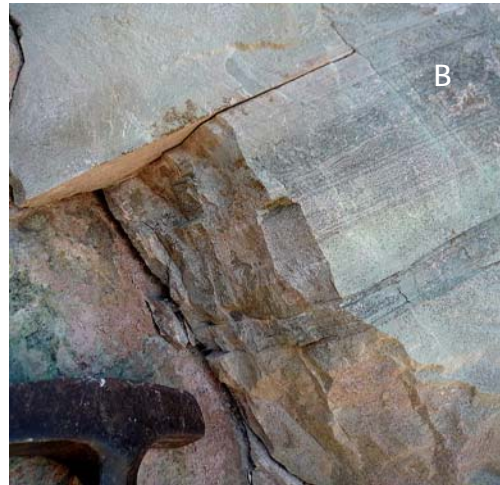


Photo 7.1.- Panoramic view of subvolcanic dikes that cut the sedimentary sequence, note also handmade labors. B) Laminations containing sulfides subparallel to bedding. C, D, E and F) Cu carbonates mineralization (malachite and azurite).

Finally the eastern side of the Andahuaylas - Yauri Batholith is characterized by contain a significant number of groups of porphyry systems also known as cluster highlighting between the main: Morosayhuas, Cotabambas, Katanga, Las Bambas and Tintaya. By isovalue maps of stream sediment has been able to recognize an important NW lineament of all cluster mentioned above.

One of the most important projects of Andahuaylas - Yauri Batholith is related to the cluster of Cotabambas, where four important mineral occurrences outcrop possibly related to a single porphyritic system. These four mineral occurrences are known as: Azullccaca, Ccaclla, Ccarayoc and Huacclle.

Geochronological studies of Perelló et al., (2003) indicate an age for the Ccalla deposit of approximately 35.7 ± 0.9 Ma (K-Ar second biotite). Age was assumed for the entire cluster of Cotabambas. Geochronological studies made in this investigation using the method Ar - Ar and Rb - Sr in the four mineral deposits showed similar results to Ccalla: 35.9 ± 0.4 Ma, Azullccaca: 35.3 ± 0.7 Ma.

These new dating show that Cotabambas Cluster and its four associated porphyry deposits belong to the same porphyritic system with the same age (peers) and the same origin (cogenetics). A very important feature of these Cu - Au deposits porphyry is a shortage of veins type EB (early biotite) and the prevalence of veins type M (magnetite). Both types of veins are directly related to potassic alteration in porphyry deposits. This same feature was observed in Au - Cu porphyry at northern Peru (Minas Conga) (Rivera, 2008; Davies, 2003).

Vetiforms systems with polymetallic mineralization (Cu - Pb - Zn) and monometallic (Au) are more abundant in the western part of Andahuaylas - Yauri Batholith. Containing in some cases grades to 5.5 g/t (Yanamina), existing rosary-like structures with grades that exceed 15 gr/t (Personal conversation with artisanal miners).

The project Tumipampa (Dynacor SAC) is an example of gold-bearing veins that in some places their grades reach up 12.25 gr/tn. Taking the model of Sillitoe (2010), this deposit would be type Au disseminated hosted in sedimentary rocks and Au / Zn - Pb distal Skarn. Most of these veins that outcrop in the Andahuaylas - Yauri Batholith and cut limestones of Ferrobamba Formation and show strong anomalies in Au / Pb, thus their mineral deposit type would be related to replacement veins or skarn mineralization of distal zoning with respect to the core of the porphyry system.



Foto 7.2.- A, B, C y D Photos of the veins that cut the limestone of the Ferrobamba formation. The Au grades exceed 5 gr/tn. (Yanamina Mine).

From the regional point of view all these mineral deposits fall inside the XV belt "Cu - Mo (Au, Zn) Porphyries - skarn and Cu - Au - Fe deposits related with Eocene - Oligocene intrusive". The metallogenetic characteristics that helped to define this belt was the following:

- An association of mineral deposits that are spacially and temporally related (middle Eocene - Oligocene) to a great batholithic body of calco - alkaline characteristic.
- This belt is limited to the north and east by regional faults: USA systems faults (Urcos - Sicuani - Ayaviri) and Abancay systems faults. The western limit and south of this belt still not this very clear, but it is restricted to the outcrop of the Andahuaylas - Yauri Batholith.
- The geochemistry features are very well-known at regional level (fire Pacific belt) that calco - alkaline magmatism is very favorable for the generation of Cu - Au - Mo porphyries systems

Its even not very clear south limit makes suppose for geochronology and space correlations that is the continuity of one of the so many Chilean porphyries belt where highlight important mineral deposits as Collahuasi district, Chuquicamata -El Abra and La Escondida (middle Eocene - Oligocene). These relationships have allowed to infer an important correlation between the porphyries of the north of Chile and the porphyries of the Andahuaylas - Yauri Batholith.

The isotopic relationships indicate until the moment that the potential of the porphyries of the Andahuaylas - Yauri Batholith are of moderate resources more or less 100,000 Tn of Cu. The minimum value of initial strontium for the deposits of the Cotabambas cluster is 0.7048, while that for El Abra (10' 000,000) Chuquicamata (+43' 000,000) and La Escondida (22' 500,000) its securities of initial strontium are less at 0.7044. The hypothesis is as much as minor is the relationship of strontium initial more probability it exists for that Peruvian deposits are similar to of Chilean giant porphyries system.

This relationship could take more consistency if the geologic conditions on which the porphyries of the north of Chile and the porphyries of the Andahuaylas - Yauri Batholith was emplacement was the same. But at the moment still exist doubts about the continental thickness for both areas it has been the same.

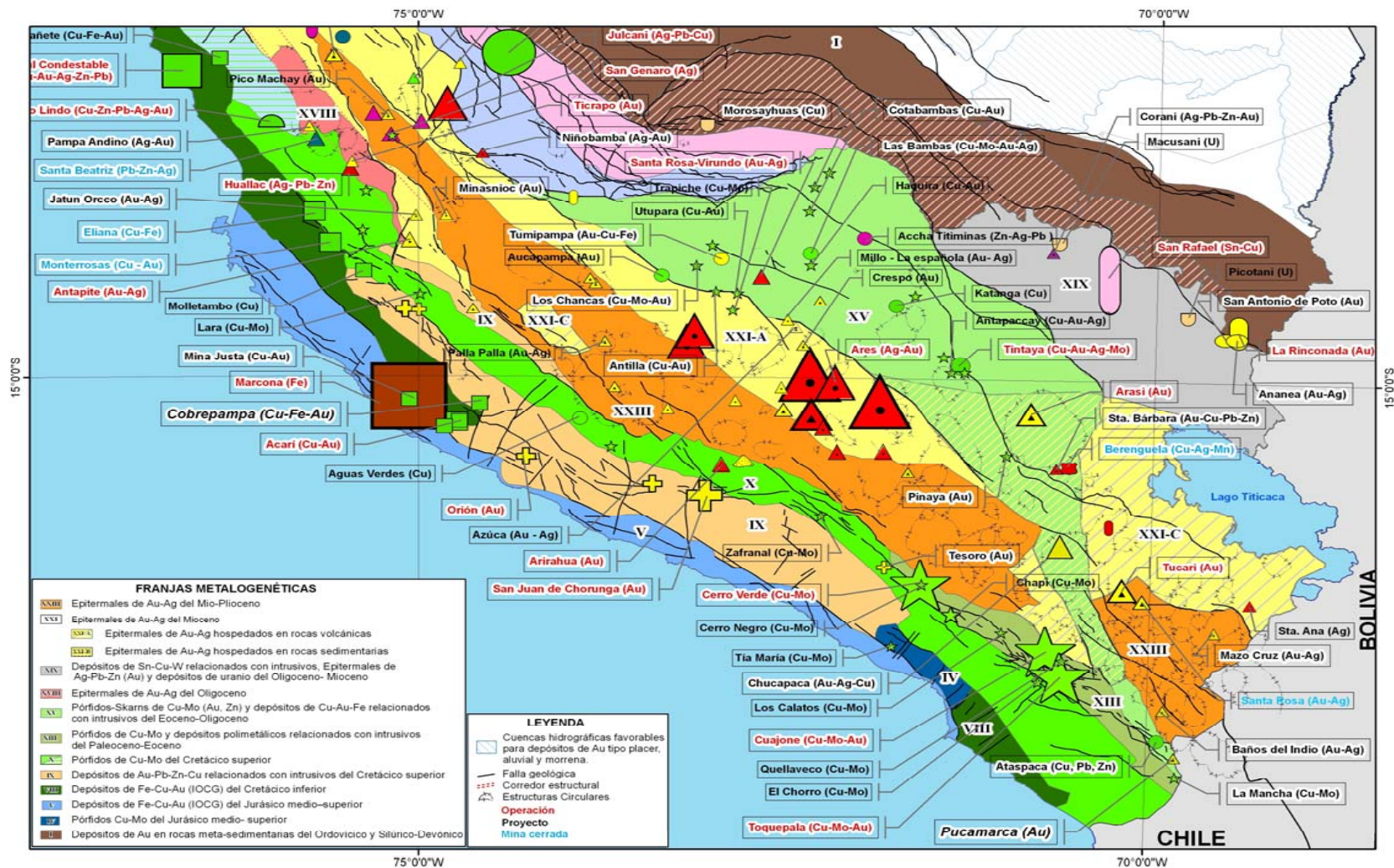


Fig. 7.2.- Metallurgical Map of the South Peru, showing the XV belt and its infer continue to north Chile where outcrop the Middle Eocene – Oligocene porphyries belt. (Acosta, et al., 2010 December version)

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