PGC
PUBLISHING

Lipten, E.J. and Smith, S.W., 2005 - The Geology of the Antamina Copper-Zinc Deposit, Peru, South America; *in Porter, T.M. (Ed.), Super Porphyry Copper & Gold Deposits: A Global Perspective*; PGC Publishing, Adelaide, v. 1, pp 189-204.

THE GEOLOGY OF THE ANTAMINA COPPER-ZINC DEPOSIT, PERU, SOUTH AMERICA

Eric J. Lipten and Scott W. Smith

Compañía Minera Antamina S.A., Peru

Abstract - Antamina is the largest known copper-zinc skarn (>3000 Mt @ 1.1% Cu and 1.3% Zinc) in the world. It is located in the Northern Andes in Peru, 270 km north of Lima. The deposit formed at approximately 10 Ma by the emplacement of quartz monzonite intrusions into Mid to Late Cretaceous limestones of the Celendin and Jumasha Formations. Mineralisation is hosted as a series of zoned green and brown garnet endoskarns and exoskarns in the form of chalcopyrite, bornite and sphalerite. Elements present within the deposit of significant quantities to affect concentrate value are Cu, Zn, Mo, Ag, Bi and Pb. Antamina produces four concentrates, namely, copper (chalcopyrite and bornite), zinc (sphalerite), molybdenum and lead-silver-bismuth.

Introduction

The Antamina Copper Zinc Deposit (9° 32´S Latitude; 77° 04´W Longitude; 4100-4700 m above sea level) is located in the North Central Andes of Peru, 270 km in a straight line north of Lima. Huaraz is the closest large city to the mine and it can be reached by direct flight from Lima or by a six hour drive. Access to the mine, east of Huaraz, is by a 3.5-hour drive on a 200 km paved road (Fig. 1).

The Antamina deposit is a very large copper-zinc skarn with silver, molybdenum, lead and bismuth formed by the intrusion of a quartz monzonite body into limestones.

The Antamina mining project is the largest industrial project ever in Peru. The investment amount for the construction phase was 2.3 billion US dollars, covering the mine site, port facilities and the 320 km pipeline which carries copper and zinc concentrates from the mine to the coast. Construction began in 1999 and on 11 July, 2001 the first concentrate was shipped from the Pacific coast Port of Huarmey. Peruvian President Toledo formally inaugurated the Antamina mine on 14 November, 2001.

Historical artisanal mining was undertaken in the Antamina Valley for several centuries. The first recorded owner and operator was Leopold Pflucker in 1850. He built a small copper and lead smelter at Juproc using coal from nearby outcrops. The Italian naturalist Antonio Raymondi visited the area in November 1860 and found the smelter to be producing lead ingots of 35 kg containing 20 to 25 ounces (0.6 to 0.75 kg) of silver.

The first company to carry out exploratory work in the valley was Cerro de Pasco Corporation, during the period from 1952 to 1971. Work was confined to the steep slopes on the East Side of the deposit where the topography allowed easy underground access by means of adits. On 30th October, 1970 all of the mining assets owned by Cerro de Pasco were transferred to the Government of Peru.

Following the expropriation, 2200 hectares of mining rights were passed to Minero Peru, the mining administration agency of the Government of Peru, which in 1974 formed the Empresa Minera Especial (EME) in partnership with the Government of Romania's mining agency, Geomin. EME carried out a careful and methodical program of work on the property culminating in a series of full feasibility studies of Antamina based on the proven and probable reserves determined from drilling and underground sampling. In 1992, Minero Peru used these studies as a basis for an attempt to market Antamina and produced an Investment Compendium that was not widely circulated, and as a result the sales effort failed. In 1993 the Antamina property was transferred to Centromin (a State owned mining corporation) and became part of a government privatisation sales package.

In 1996 Rio Algom Limited and Inmet Corporation, both of Canada, successfully bid for the property and immediately formed Compañía Minera Antamina (CMA) as a 50:50 owned joint venture. In 1998, Inmet sold out its interest in Antamina to two other Canadian companies and CMA was restructured under an ownership of 37.5% Rio Algom, 37.5% Noranda Inc., and 25% Teck Corporation. In 1999, the ownership was further modified when each of the 3 partners sold portions of their interest to Mitsubishi Corporation, resulting in an ownership breakdown of 33.75% Rio Algom, 33.75% Noranda, 22.50% Teck, and 10% Mitsubishi.

In 2000, Billiton Plc of Great Britain bought 100% of Rio Algom Limited thereby effectively becoming one of the partners. Billiton and BHP merged as did Teck and Cominco, resulting in the current ownership of CMA: 33.75% BHP Billiton, 33.75% Noranda, 22.50% TeckCominco, and 10% Mitsubishi.

Regional Metallogeny

Antamina lies within the eastern part of the polymetallic belt of North Central Peru. This belt is located in the Western Cordillera between about 6°S (the Huancabamba Deflection) and 14°S (the Abancay Deflection) and is defined at either end by transverse, arc normal structural features. Mineralisation in the belt shows a Zn-Pb-Ag-Cu-Au association, mainly in hydrothermal deposits related to Middle to Upper Miocene calc-alkaline subvolcanic and high level intrusions.

The belt was traditionally known for major Zn-Pb-Ag mines such as Cerro de Pasco, Milpo, Casapalca-Morococha and others, although porphyry Cu and Cu-Au deposits also occur. Over the past decade it has become the major gold producer in South America with the discovery of epithermal gold deposits such as Yanacocha, Pierina, Quicay and Alto Chicama. The ore deposits of the belt are characterised by significant amounts of other associated metals, some of which may be produced as by-products at different mines. These include Bi, Cd, Se, Te, Sb, In, Hg, Ge, Sn, W, Mo and As. A number of currently operating mines and past producers, including Contonga, Huanzala and Pachi Pachi (Fig. 1), are situated proximal to Antamina.

Regional Geology

The Antamina deposit is located in the Andes mountain belt, which is situated on the Pacific margin of South America, where the oceanic Nazca Plate is being subducted to the east under the continental South American Plate. Plate collision and subduction zone melting have been responsible for the folding and faulting, mountain uplift, volcanism, plutonism and the majority of the mineral deposits of the Andes. North Central Peru, where Antamina is located, is a seismically active zone but does not currently have any active volcanoes.

The Andes of North Central Peru comprise from west to east, the Coastal Zone (desert), the Western Cordillera (Cordillera Occidental) and the Eastern Cordillera (Cordillera Oriental). Antamina lies in the eastern part of the Western Cordillera.

The Western Cordillera is composed of two main mountain chains. The Cordillera Negra in the west is separated from the Cordillera Blanca in the east by the valley of the Rio Santa (Huaraz valley). Antamina is situated east of the Cordillera Blanca between it and the valley of the Marañon River, which in turn separates the Western and Eastern Cordillera.

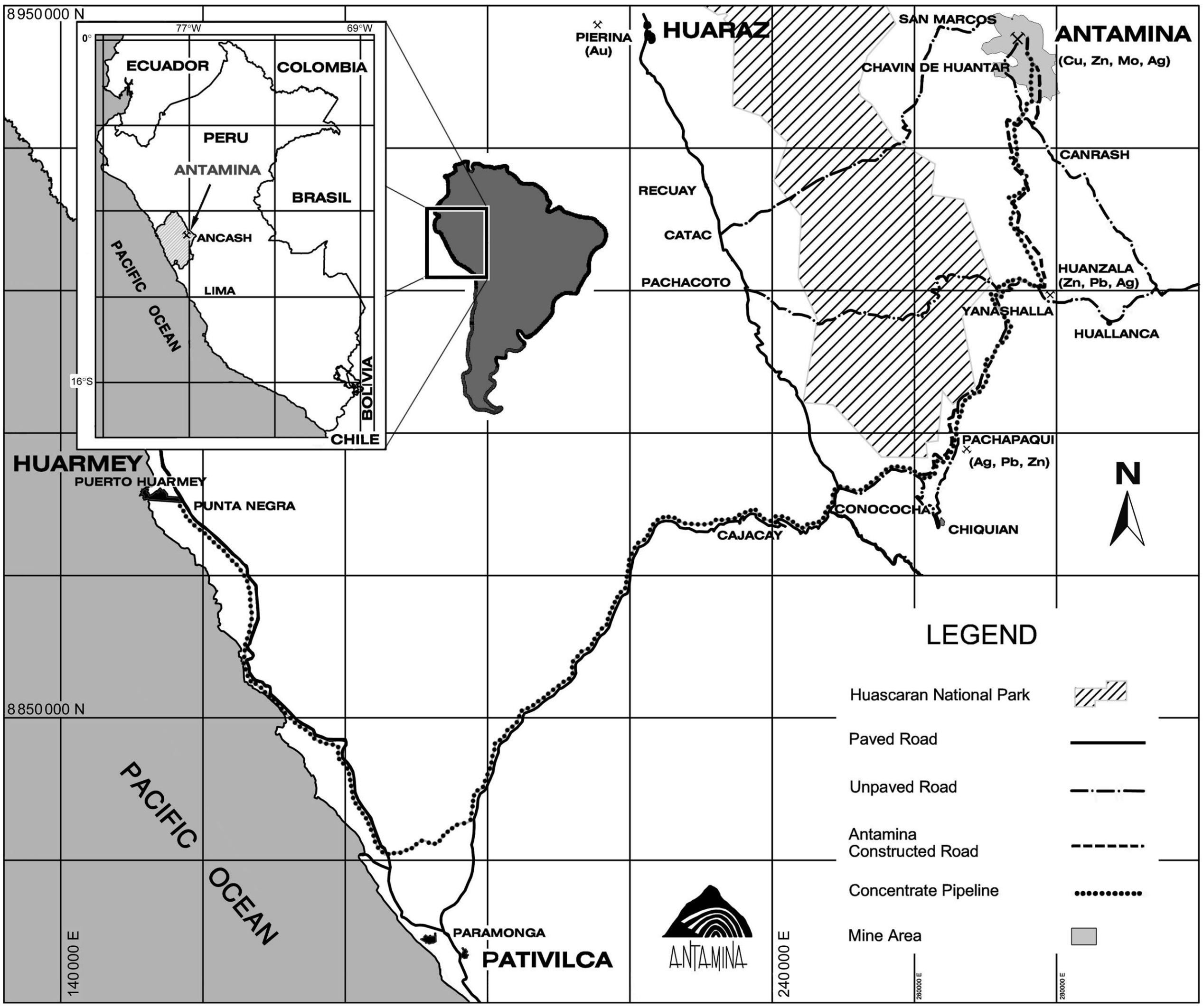

Figure 1: ***Location Map of the Antamina Mine***

Between Antamina and the Pacific Ocean lies the Coastal Zone and the Cordillera Negra. Together these form a magmatic arc that was active from the Late Jurassic to the Tertiary. The main components of this arc are the Casma Volcanics (Albian, ca 105 to 95 Ma), the Coastal Batholith (ca 100 to 50 Ma) and the Calipuy Group Volcanics (Late Cretaceous to Paleogene, ca 95 to 30 Ma). The latter form the Cordillera Negra. The arc was deformed during the mid-Cretaceous (Mochica Phase) and Late Cretaceous (Peruvian Phase).

To the east of the magmatic arc, thick sediments were deposited in a deep, extensional, ensialic marine back-arc basin called the Western Trough (or Western Peruvian Geosyncline), also active from Late Jurassic to Late Cretaceous times. The sediments consist of slates and quartzites (Chicama Formation, Late Jurassic, ca 152 to 144 Ma) followed by thick deltaic sandstones, shales and coal with a marine limestone (Goyllarisquisga Group, Early Cretaceous, ca 144 to 114 Ma). Next came a marine transgression and deposition of thick marine carbonates (Mid Cretaceous, ca 113 to 88 Ma, Pariahuanca, Chulec, Pariatambo and Jumasha Formations), followed by marine shales with carbonates (Celendin Formation) in the Late Cretaceous (ca 88 to 84 Ma). Following marine regression and basin uplift, there was deposition of continental red bed sediments (Casapalca Formation) in the Late Cretaceous and Paleocene. The Antamina deposit is hosted near the contact of Jumasha Formation and the younger Celendin Formation, both of which are composed of limestones and limey shales, and are situated in the eastern part of the Western Trough (Fig. 2).

This basin was bounded to the east by a basement high (the Marañon High, Axial Threshold or Marañon Geanticline) formed of Late Precambrian schists, phyllites and slates (Marañon Complex), which now forms the Eastern Cordillera where the overlying Mesozoic sediments are much thinner. To the east, a sequence of Mesozoic sandstone and carbonates was deposited in an external foreland basin (the Eastern Basin or Eastern Peruvian Geosyncline) onlapping the Brazilian Shield. This sequence is thinner than that of the Western Trough and now forms the Sub-Andean Zone fold and thrust belt.

The Western Trough was deformed by the Inca 2 fold phase (Incaian) in the Late Eocene (ca 41 - 40 Ma). This resulted in extensive folding and reverse faulting throughout the basin and the formation of a fold-thrust belt in the eastern part along the boundary with the Marañon High (Marañon Fold-Thrust Belt). Antamina is located in this fold-thrust belt. During the Miocene there were three short compressive periods (Quechua 1 to 3) at ca 19 Ma, 12 Ma and 6 Ma, separated by neutral or extensional periods.

In the Middle to Late Miocene, the Cordillera Blanca batholith was intruded in the eastern part of the Western Trough sequence (Chicama Formation) to form the Cordillera Blanca (ca 16.5 to 5 Ma), with coeval ignimbrites (Yungay Formation). At the same time there was widespread magmatism (middle- to high-K calc-alkaline) throughout the Western and Eastern Cordilleras. The Antamina stock is a part of this latter phase.

Local Geology

The oldest landform in the eastern part of the Western Cordillera, where Antamina is situated, is the Puna Surface. This is the remnant of a peneplain of regional extent now shown by concordant mountain peaks. Around Antamina the peaks are generally at an altitude of 4500 to 4700 m above sea level.

The Puna Surface is cut by the Valley and Canyon phases, which formed the major river valleys in the region such as the Marañon and Santa. The high parts of valleys formed in the Valley Stage are broad and open, and usually populated and cultivated. The lower parts are narrow canyons, formed as a result of rapid uplift and erosion. They can be up to 2000 m deep. The Puna Surface has been dated as younger than 14.5 Ma, the Valley Phase as post 14.5 Ma to pre 6 Ma, and the Canyon Phase as post 6 Ma.

The youngest features are from the Pleistocene glaciation with an ice-limit down to an altitude of about 3500 m. There were at least three phases of glaciation. The main phase formed U-shaped valleys a few kilometres long such as those at Antamina (4100 - 4200 m) and Contonga (Lake Pajosccocha at 4110 m). A younger glaciation formed corrie (cirque) basins such as Lake Antamina (4337 m), Lake Contonga (4380 m) and the lower Condorcocha valley (4360 m). The last phase formed small corrie basins at lake Condorcocha (4510 m) and Contonga (4620 m). The Antamina valley feeds into a series of deep valleys formed during the earlier Valley and Canyon stages. It is probable that a small valley of this stage existed at Antamina prior to glaciation, allowing ice to accumulate.

The stratigraphy of the Antamina district is shown in Fig. 3. Antamina is located within one of the widest parts of the Marañon Fold-Thrust belt, where it has a width of about 40 kilometres, although elsewhere the same belt can be as narrow as 10 km. The structures and stratigraphy trend NW-SE and the thrusts are east verging. The age of thrusting is Incaic 2 (Late Eocene).

The Antamina deposit is hosted near the Incaian contact of the Jumasha and Celendin Formations. The Jumasha Formation is thrust over the younger Celendin Formation in a number of sections and at Antamina the exact contact is yet to be agreed, due to a lack of exposure. West of Antamina the Jumasha Formation forms a steep thrust ramp over the Jumasha thrust tongue (i.e. over itself) and the Celendin Formation. The Jumasha forms prominent steep mountains of well-bedded, light grey limestone. Continuing west, successive thrusts bring in the Pariahuanca Formation over the Jumasha (the Chulec and Pariatambo Formations are missing), the Carhuaz and then the Chimu Formation. The latter forms a synclinorium with the Santa and Carhuaz Formations outcropping to the south. Further west the Oyón Formation is thrust over the Chimu Formation (Fig. 4).

The Celendin Formation outcrops to the east of Antamina where it is soft with little exposure and forms the core of a regional synclinorium. The axis plunges gently to the southeast and runs along Quebrada Huincush to Rosita de Oro and must continue beneath the Antamina thrust tongue since Quebrada Tucush is on the north limb of the syncline.

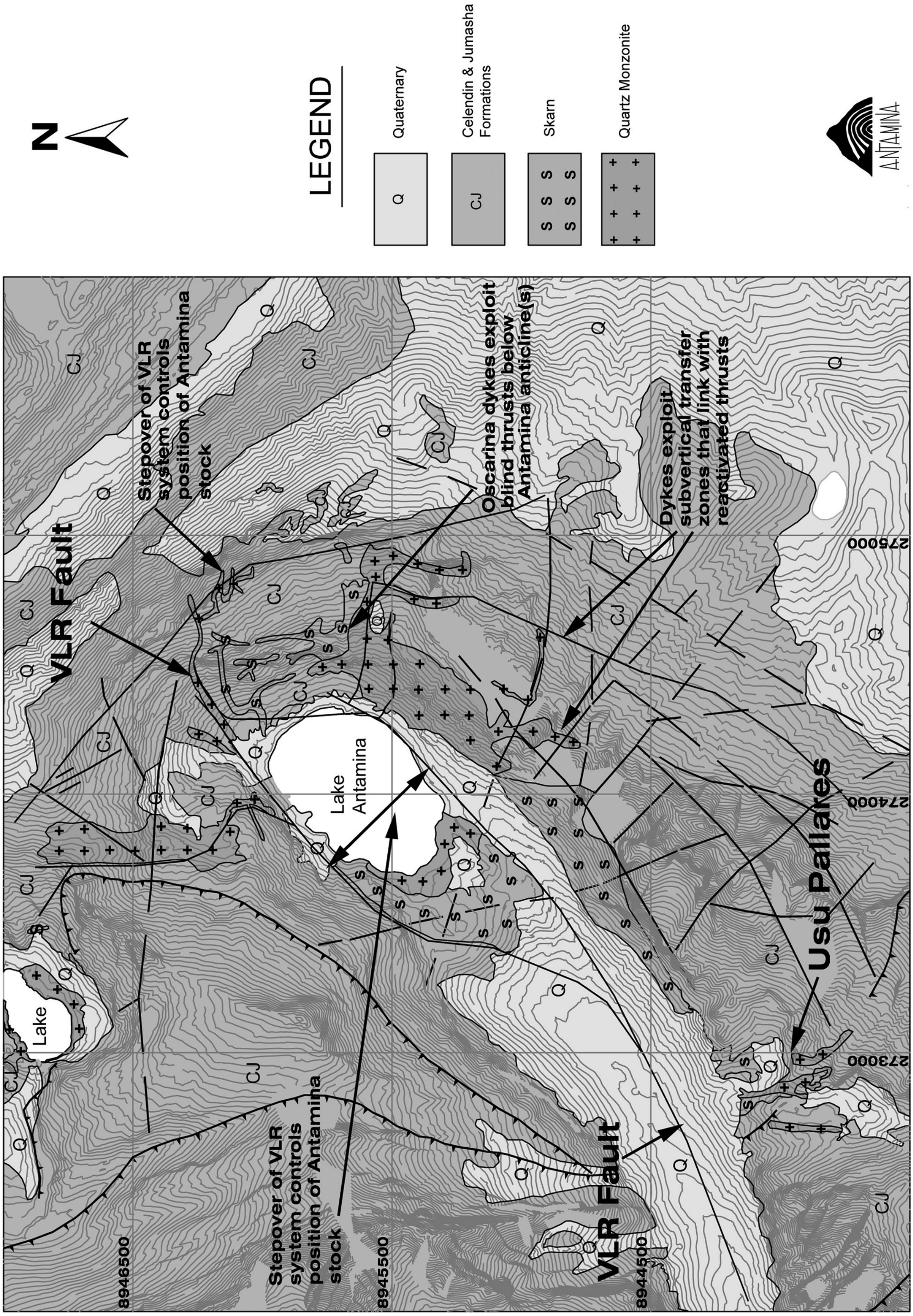

Figure 2: ***Antamina District Geology Map***

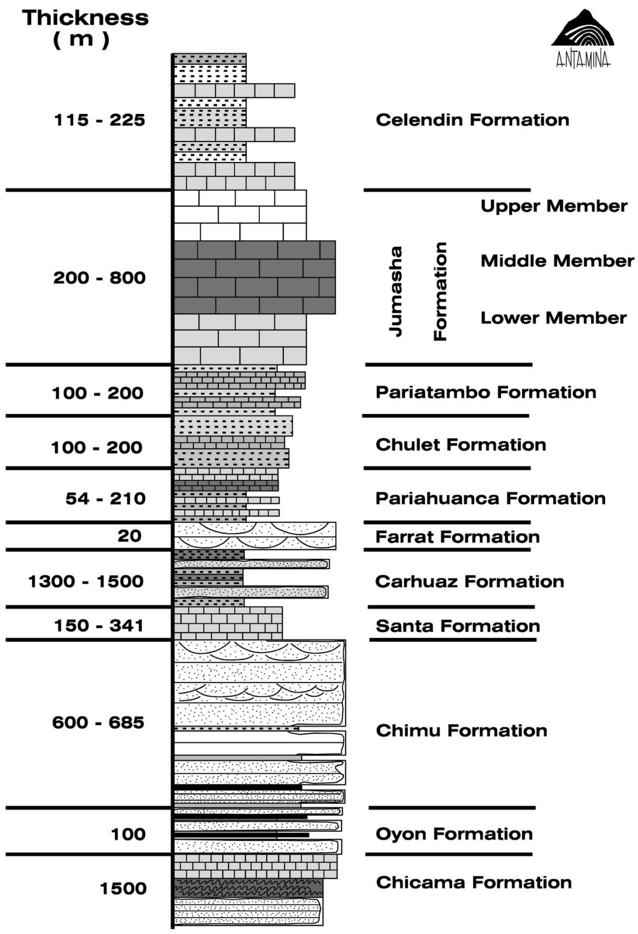

Figure 3: ***Stratigraphy of the Antamina District***

The actual trace of the fault separating the Celendin and Jumasha Formations northeast of Antamina Lake appears to be quite steep. It is not clear whether this is merely a steep ramp of the thrust or a later normal fault offsetting the thrust.

The syncline closure in the northwest around Contonga has very complicated minor folding in the Jumasha Formation. Further east, the Celendin is in stratigraphic contact with the Jumasha and Crisnejas Formations (the latter is the eastern facies of the Chulec and Pariatambo Formations) and is thrust eastwards over an anticline of the Chim, Santa, Carhuaz and Crisnejas Formations.

The Antamina Cu-Zn skarn deposit is developed on the margins of a multiple phase quartz monzonite porphyry, the Antamina intrusion (9.8 Ma, McKee *et al.,* 1979). Another intrusion with a similar composition, 1.5 km NW at Condorcocha, is only accompanied by a narrow, weakly mineralised skarn.

The Contonga and Taully stocks lie 4 km north of Antamina and intrude the Jumasha Formation limestone. Both have a quartz monzonite composition with textures varying from porphyritic to equigranular, and phyllic alteration. The stocks are small (300 m and 650 m diameter respectively) and form subvertical cylinders with a narrow ring of garnet skarn (average 3.2 m wide) with Zn-Ag-Pb-low Cu mineralisation, which has been mined at Contonga.

The Lucia pluton (Estella del Norte property), located about 7 km southeast of Antamina, is a relatively large mass (4 x 2.5 km) of quartz monzonite and granodiorite which is equigranular in the main body but has a porphyritic texture in its north-western part. It intrudes Jumasha Formation limestone and has narrow garnet skarns developed at the contact over widths of 0.5 to 2.5 m and lengths of hundreds of metres, as well as veins in the limestone. The skarns have Zn-Pb-Ag mineralisation with low Cu. There has been no mining apart from some small prospect workings near the contact of the Lucia pluton.

Deposit Geomorphology

The Antamina valley is a 4 km long U-shaped glacial valley with steep sides, a flat floor and corrie lake in an upper valley at it's head. The lake surface was 4337 m (August 1996), while the lake itself was 760 m long by 510 m wide and up to 51 m deep. It was separated from the main valley by a rock ridge, known as the Taco (4375 m), which was 38 m above the lake level and 155 m above the main valley. The northwestern part of the ridge is ice smoothed rock outcrop with roches moutonnées, while the southeastern half has moraine deposits and the lake spillway. This was an outlet from the corrie glacier as an ice tongue or stream.

The main Antamina valley altitude varies from 4200 m to about 4100 m and has a gentle gradient. There are two hanging valleys, Usu Pallares and Vallesito.

The head of the Antamina valley (northeast) is a sharp ridge with an altitude of 4640 m to 4717 m above sea level. Ridges and peaks rise up to 5073 m (Cerro Tornillo) to form the northwestern side of the valley, while the ridge on the southeastern side varies from 4683 m up to 4924 m (Cerro Buque Punta).

The Antamina valley thus has a depth of 500 to 600 m below the enclosing ridges and up to almost 1000 m below the highest peak. The pre-glacial topography is interpreted to have been a Puna Surface at around 4700 m with peaks over 5000 m, cut by a small, shallow, headwater river valley at Antamina during the Valley and Canyon Phases. Ice accumulated in this valley during the main Pleistocene glaciation, gouging out the main and hanging valleys.

The Antamina deposit was probably not exposed before the first glaciation, which is interpreted to have unroofed the deposit and exposed fresh sulphides. This is evidenced by the presence of fresh sulphides in a carbonate matrix of the first moraine. During the interglacial interval there was a period of oxidation of the freshly exposed sulphides resulting in the formation of ferricretes. This oxidation zone was partly removed by a second corrie glacier, as shown by the limonitic moraine from this stage.

Moraines from both glaciations outcropped on the southeastern side of the Taco rock barrier below Lake Antamina. The older moraine is pyritic and the younger is limonitic and in places there was a ferricrete layer between the two.

The lower slopes of the valley sides have lateral moraines, talus deposits and colluvium, which are generally fine

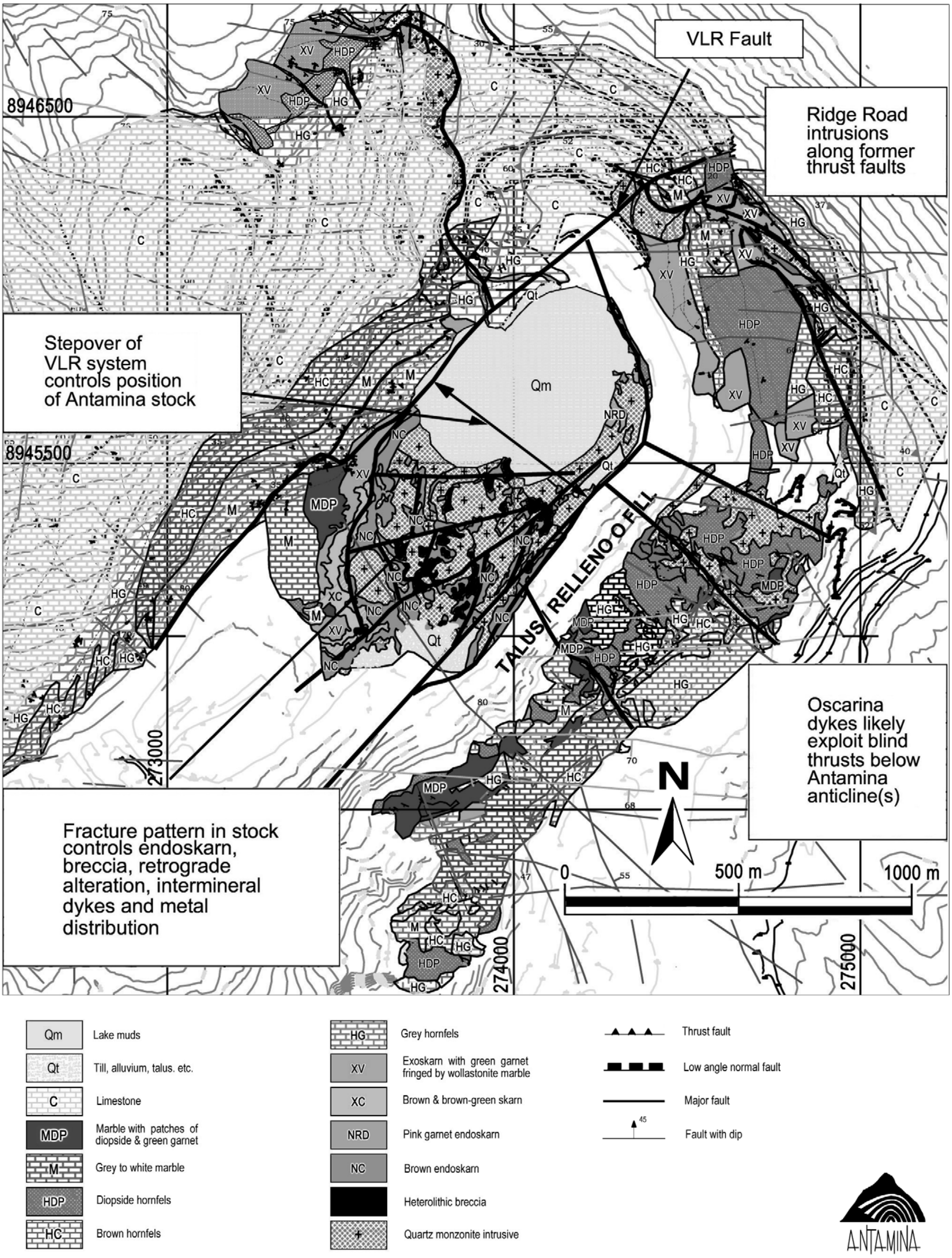

Figure 4: ***Deposit Geology of the Antamina Mine Area with Interpreted Structure***

grained. There are ferricretes up to several metres thick with slope-parallel bedding on pyritic bedrock in the Laberinto and Oscarina areas. The upper, steep valley sides are either bare rock or have talus deposits and locally thin soil cover.

The bedrock profile of Lake Antamina consisted of two U-shaped channels with steep sides. Vertical holes drilled from barges on the lake in 1999 showed the floor to be underlain by sediments which were up to 45 m thick. These sediments were composed of bedded silt-clay and talus material, both of which contained abundant local sulphides.

The bottom of the Antamina valley had a pyritic moraine on bedrock, overlain by thin peaty sediments. Overburden thickness was up to 36 m, but overall averaged approximately 8 metres. At the southwestern end of the valley there were rock falls with blocks up to 25 metres across, derived from the steep slopes of the steeply dipping limestone beds west of the main thrust. There are moraines below the Usu Pallares hanging valley (located at the southeast end of the Antamina valley), however there are no moraines below the main Antamina valley or below the Vallesito hanging valley (located at the southwestern end of the Antamina Valley). These valleys drop straight into the deep river valley where the glacial debris was washed away without being deposited.

Deposit Geology

Several critical lithological distinctions have been detected within the ore deposit, including the discrimination of exoskarn from endoskarn, and the recognition and systematic identification of breccias in the orebody. These distinctions are considered important from a resource modelling as well as an ore-genetic point of view because of apparent differences in the grade and style of mineralisation in the various rock-types as described below. There are currently 156 rock/sub-rock types identified and logged within the Antamina deposit. Procedural control and logging consistency is enforced through rigorous application of the CMA Core logging manual (Antamina, 2000).

The general skarn zonation from the intrusive core outward is as follows: brown garnet endoskarn, mixed brown and green garnet indeterminate skarn, mixed brown and green garnet exoskarn, green garnet exoskarn, diopside exoskarn, wollastonite exoskarn, hornfels, marble, limestone. Heterolithic breccia composed of all skarn types can occur in any lithology type (Figs. 5 & 6).

Intrusive

The Antamina intrusion was previously divided into Early-mineral, Inter-mineral, Late-mineral and Post-mineral phases, each divided into several sub-phases, primarily on the basis of the degree of alteration, the intensity and type of veining, the associated mineralisation and location (Pacheco, 1997). Currently an empirical classification of the intrusive rocks based on their petrography rather than one based on time inferences is used. Four main types of intrusive rock are recognised. These are used in all of the re-logging, and are distinguished on the basis of phenocryst type and abundance. They are: i) crowded plagioclase porphyry, ii) crowded plagioclase K-feldspar porphyry, iii) crowded plagioclase K-feldspar-megacrystic porphyry, and iv) sparsely porphyritic plagioclase K-feldspar

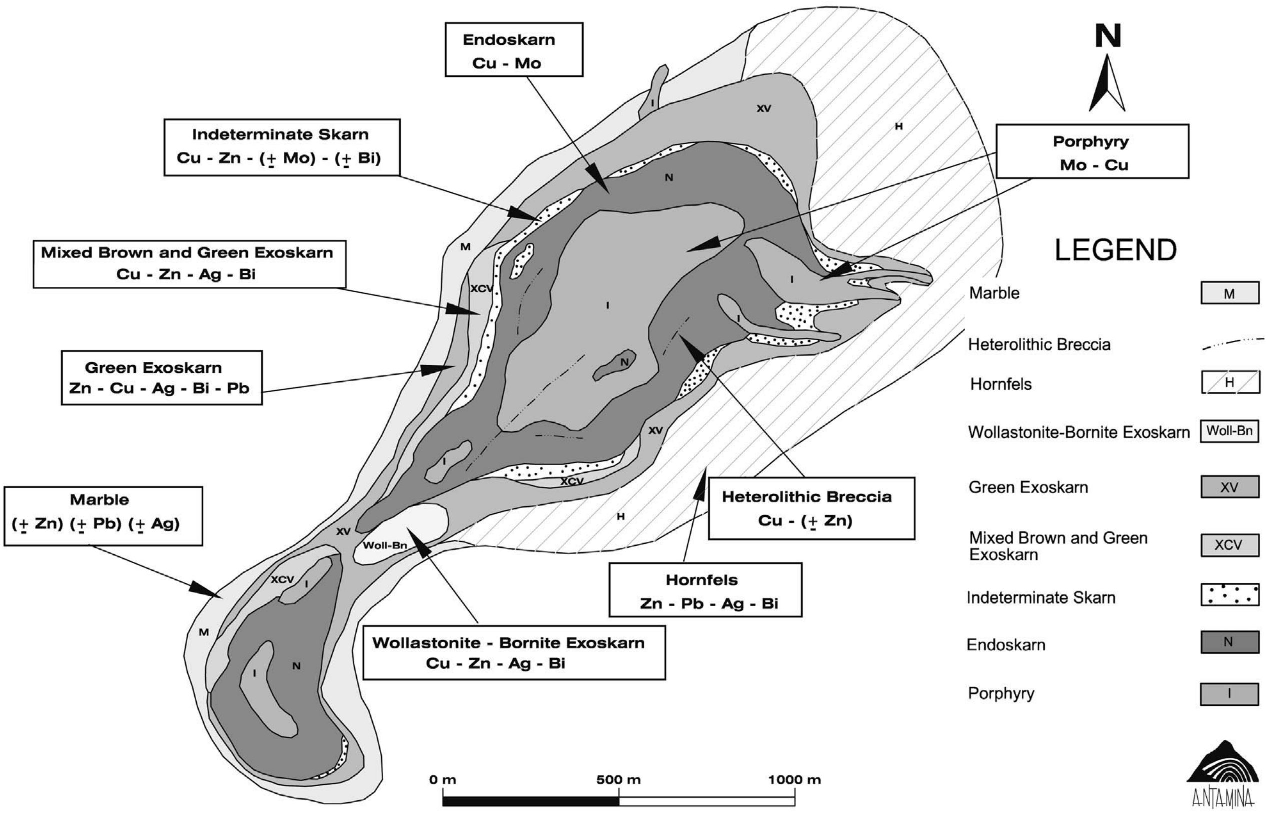

Figure 5: ***Schematic Plan of Lithology and Metal Zonation***

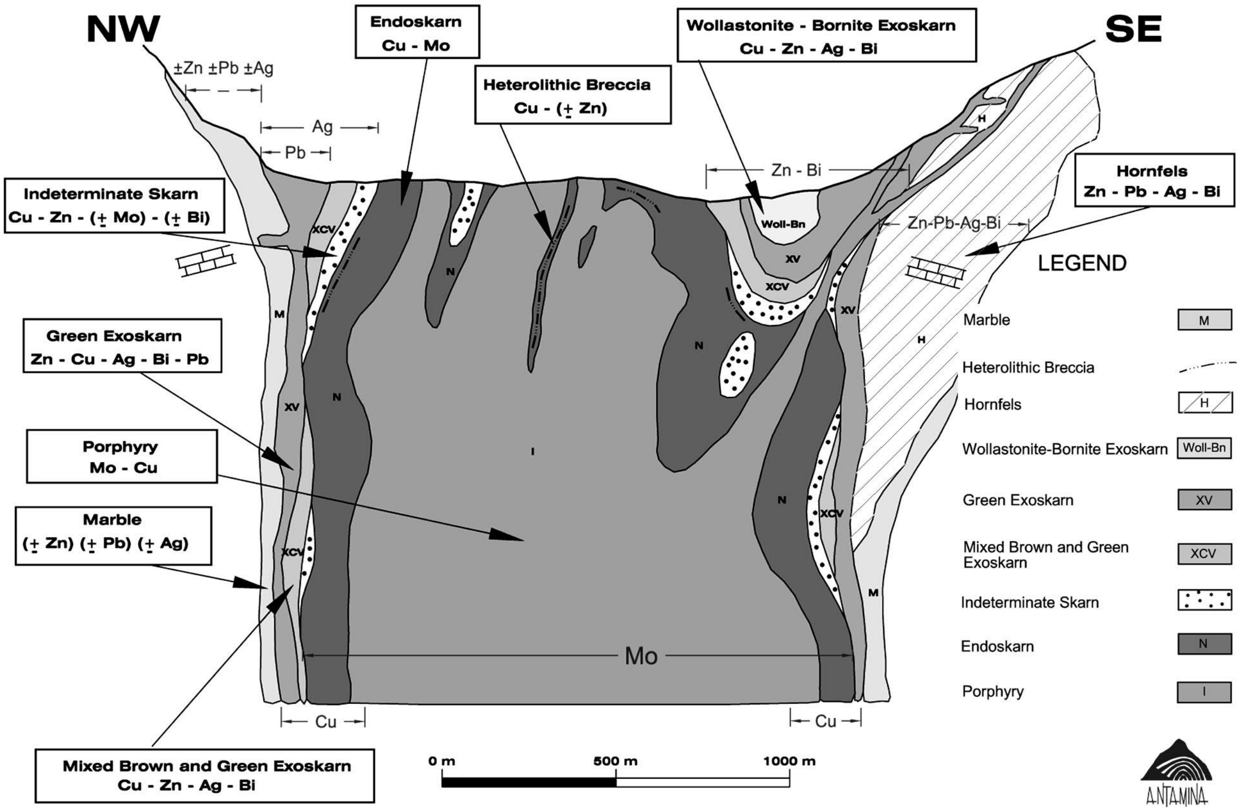

Figure 6: ***Schematic Section of Lithology and Metal Zonation***

porphyry. A minor intrusive rock-type, sparse hornblende plagioclase porphyry, forms a dyke in the Poderosa area, at the NE end of the Antamina valley.

The main mass of the un-skarned porphyry is predominantly crowded plagioclase porphyry with common quartz, biotite and relict hornblende phenocrysts, and rare K-feldspar phenocrysts. The K-feldspar phenocrysts are locally more common and thus another sub-unit of crowded porphyry has been distinguished. Sharp contacts between these two types of crowded porphyry are very rarely evident. Apparent magma co-mingling textures between a minor phenocrysts-poor darker-grey phase and a paler phenocrysts-rich phase are displayed locally.

Although the contact relationships among the different porphyry phases are not everywhere clear, in general the crowded plagioclase porphyry is the earliest phase, and the sparse porphyry, the latest. Locally, crowded-porphyry contains quartz vein stockworks and associated biotite, i.e., potassic alteration. This altered but un-skarned porphyry locally hosts disseminated and vein molybdenite mineralisation and minor disseminated chalcopyrite (≤ 0.2% Cu and 0.03% Mo). Sparsely porphyritic dykes cut crowded porphyry, skarn and breccia, and locally contain skarn xenoliths.

Although some aspects of the relationship between the porphyry-style alteration and mineralisation to the skarn alteration and economic Cu-Zn mineralisation remain unclear, the porphyry Mo mineralisation generally appears to be overprinted by skarning. Significant intervals of prograde coarse-grained endoskarn occur without Cu mineralisation, and almost all Cu mineralisation in unbrecciated endoskarn is vein-controlled and accompanied by retrograde alteration. Phyllic alteration in the porphyry is rare and may be proxied for by the retrograde skarning.

Multiple intrusions are typical of porphyry deposits. At Antamina the different phases were probably intruded within less than one million years (they are statistically identical in radiometric dating). The relative ages of intrusion are recognised by textures such as cross-cutting relationships, xenoliths, chilled margins, truncated veinlets, degree of quartz veining and hydrothermal alteration, igneous texture and overall rock quality.

A USGS study in the 1970´s addressed the question of the age of the Antamina intrusions. It was dated by K-Ar at 9.8 Ma (mean of 9.1 ±0.4 Ma to 10.4 ±0.4 Ma, from 5 samples) with no significant differences between primary biotite, primary K-feldspar and K-feldspar megacrysts, nor between different intrusive phases (quartz monzonite porphyry in Taco - Laberinto; late mineral quartz monzonite with K-feldspar megacrysts in Usu Pallares; and minor intrusions with no quartz phenocrysts north of the lake) (McKee *et al.,* 1979).

The intrusives have a complicated shape in the upper part of the deposit, which is believed to be a result of strong structural control on emplacement and multiple phases of intrusion. The main trend of the intrusive bodies and edges is NE, although there are also E-W and NW trends. At high levels (e.g. at 4260 m) the intrusion is composed of several discrete broad dykes with a dominant NE trend, but also SE and E-W local trends and edges. The dips vary from vertical to moderately inclined (ca 45°). The skarn around and above these has widths of 70 to 800 m at this level. The intrusive bodies form broad dykes that converge into a stock at depth (below approximately the 4200 m level).

Interpretations from drilling suggest that the intrusion forms an almost circular, but slightly NE elongated stock, some 800 m by 750 m in diameter at the 3900 m level. There is a 350 m long, NE-trending intrusive spur (150 m wide) at the NE end of the Lake Zone, and a 500 m long, SW-trending spur (50 - 170 m wide) below the valley at the SW end. In total the intrusions extends over a length of 1700 m at this level with little variation in the shape down to the 3850 m level. Skarn forms a 300 to 400 m wide shell surrounding the intrusions. There are separate intrusions in the Valley and Usu Pallares Zone.

The roof of the intrusion is preserved with skarn on top of it in the upper sections in the Lake and Taco areas. At this level structural control is very strong and the porphyry has intruded along the multiple structures, often as narrow bodies which are too small and discontinuous to portray in the final geological resource model.

Two possible key factors in the development and preservation of a large skarn orebody at Antamina are good structural preparation of the country rock for intrusion (allowing a complicated intrusive shape and a high intrusion to limestone contact area), and erosion to the level of the roof zone of the intrusion (preserving flat skarn bodies on top of the roof as well as steep skarn bodies at the sides of the intrusion).

Endoskarn

Two widespread types of endoskarn are recognised at Antamina. The first is a coarse-grained pink garnet variety, which consists of a milky-white plagioclase-rich matrix (distinguishable from the pale-grey, translucent matrix of un-skarned porphyry) enclosing large pink garnets and more sparse maroon garnets, and displays relict porphyritic texture. Significant mineralisation does not appear to be associated paragenetically with the development of coarse-grained endoskarn, which, although commonly containing disseminated molybdenite, only rarely hosts blebs and/or veinlets of chalcopyrite associated with epidote. It achieves importance as an ore-host because of later sulphide veins, which are associated with retrograde alteration and locally comprise sheeted arrays.

Narrow intervals of plagioclase endoskarn commonly occur between porphyry and coarse-grained pink-garnet endoskarn. Plagioclase endoskarn rarely contains ore-grade Cu, and entirely lacks Zn, but is a useful indicator of proximity to ore.

The second major type of endoskarn is a fine-grained dark-pink garnet variety that commonly hosts crackle or mosaic breccia and constitutes many of the fragments in heterolithic breccia bodies cutting intrusive rock. Fine-grained pink endoskarn is distinguishable from coarser-grained plagioclase - or pink-garnet endoskarn, on the basis of colour, grain-size, mineralogy and relict porphyritic textures. The simplest explanation for its origin is that it formed through interaction of the porphyry with brecciating fluids. However, it may have formed adjacent to structures that later focussed or controlled brecciation.

Porphyry-style Mo mineralisation, as disseminations and veins, is overprinted by endoskarn, and the veins are rendered indistinct because quartz was consumed in the skarnification. The greater part of the Cu mineralisation in endoskarn is later than the Mo, consists of pyrite - chalcopyrite (±magnetite) veins, and is associated with retrograde alteration.

Indeterminate Skarn

A further skarn type is recognised, whose origin is indeterminate. It is commonly brown, medium-grained and granular, but overall is variable in texture, grain-size and colour. Granular, medium-grained, brown garnet skarn with intergranular chalcopyrite would be classified as brown garnet exoskarn where it constitutes the end-member of a continuous gradation from green garnet exoskarn. Fine-grained, dark-pink garnet skarn having veins with chloritic selvages but lacking relict porphyritic texture would be classified as endoskarn if it were in gradational contact with porphyry. Locally the sparse maroon garnets in coarse-grained pink garnet exoskarn are larger and more abundant and they coalesce to form granular, medium-grained intervals of skarn, which appear quite similar to exoskarn. Fine-grained, pale-brown skarn would be classified as exoskarn if it constituted part of a gradation from limestone or hornfels. However, in rare locations, fine-grained, pale-brown skarn also occurs in gradational contact with porphyry and containing relict porphyritic texture. Every gradational variation amongst these skarn types occurs, and if the critical characteristics and/or gradational variation relationships for interpreting the skarn as endo- or exoskarn were absent or ambiguous then the unit was classified as indeterminate skarn.

It is hypothesised that where skarnification was very intense, both endoskarn and exoskarn approached the same composition and the mineralogy and the two facies became indistinguishable.

Indeterminate brown and green skarn usually contains pale-brown or beige, coarse- to very-coarse-grained garnets with intergranular medium- to dark-green garnets. Under the northern part of Lago Antamina, and locally elsewhere in proximity to endoskarn, this indeterminate brown and green skarn contains diopside, in part as radial clusters.

In the indeterminate mixed green and brown garnet exoskarn, brown garnet commonly occurs as veinlets cutting green garnets. In places brown garnet preferentially replaces some layers in green garnet exoskarn at a centimetre-scale, producing banded brown and green garnetite. This facies may contain sphalerite ±chalcopyrite with the same style of mineralisation and grades as green garnet exoskarn.

Brown Garnet Exoskarn

The rock-type classified as brown garnet exoskarn is texturally identical to, and grades in colour into, green garnet exoskarn. It appears to form the innermost zone of exoskarn, between an inner annulus of endoskarn (around a relatively unaltered porphyry core) and an outer shell of green garnet exoskarn and in places, wollastonite skarn. Locally it grades inward into brown indeterminate skarn. Brown-garnet exoskarn (sensu stricto) is much rarer than was originally estimated from the 1996-1997 core logging.

Green Garnet Exoskarn

In much of the deposit, the skarn facies adjacent to marble or hornfels is a green garnet skarn. In this facies, garnet commonly appears to replace calcite directly, i.e., there is no evidence that garnet replaced wollastonite. It is believed that green garnet exoskarn in different parts of the deposit formed by two different reaction paths, one, mentioned above, via wollastonite skarn, and the other, directly from marble. The two types are texturally indistinguishable.

Green garnet skarn contains either chalcopyrite-sphalerite ore or sphalerite alone, with the sulphides ranging from disseminated to massive and interbanded with green garnet. Sphalerite typically averages 3-5% in green-garnet exoskarn. However, it is erratically distributed, commonly occurring as rich bands separated by relatively barren sections.

Wollastonite Exoskarn

Wollastonite skarn occurs as an inner zone (contiguous with green garnet skarn) of bornite ore and as an outer zone (closer to marble) of bornite-sphalerite. The contact between wollastonite skarn and green garnet skarn is a broad gradational replacement interval where green garnet replaces wollastonite, and is classified as wollastonite-green garnet skarn. Bornite ore occurs throughout this intermediate zone as well as in both green garnet exoskarn and wollastonite exoskarn. The contact between bornite and chalcopyrite ores is a broad, gradational zone of coexisting chalcopyrite-bornite, generally within green garnet skarn and near wollastonite skarn. Zones of wollastonite-brown garnet skarn are also known (as both endoskarn and exoskarn) with bornite, although this skarn unit is far less abundant than the wollastonite-green garnet skarn unit.

A second variety of breccia is documented, wollastonite breccia, in which comminuted wollastonite constitutes the matrix. Because of the textural similarity of this breccia type to the more common garnetiferous heterolithic breccia, this could also represent a phreatic hydrothermal breccia. This type of breccia is distinguished by the absence of magnetite.

Diopside Exoskarn

Diopside characterises the outermost zone of exoskarn. This unit is located predominantly on the northern and eastern flanks of the deposit and comprises of a pale green diopside with calcite, quartz and wollastonite. It is generally only weakly mineralised, occasionally reaching levels sufficient to be considered ore grade and is the outer most skarn lithology related to the hydrothermal event that formed the Antamina deposit.

Hornfels

Fine-grained hornfels can be pale-brown, pale-green, grey, khaki, or yellowish-grey, and varies from fine-grained to aphanitic. It ranges from massive to laminated, with fine, wavy, compositional banding, and generally consists of a very fine-grained aggregate of garnet, phlogopite and diopside with minor wollastonite. It has been identified locally at or near the margins of the deposit. This rock has no apparent porosity or permeability, only contains rare, minor sulphides and almost never reaches ore grade. Where these layers occur on the margins of the intrusion, they appear to limit development of the ore. One can suspect that the process of hornfels formation rendered these units impermeable to further fluid flow and/or un-reactive and thus limited ore formation in them. They are thought to be of thermal metamorphic origin as opposed to the diopside skarn described above, which is metasomatic in origin.

Limestone/Marble

Most limestone/marble cut by drilling at the margins of the skarn is light grey, very fine grained and micritic with parallel bedding on a scale of several centimetres but contains no fossils, shell fragments or other biogenic or sedimentary structures. In outcrop in the upper valley slopes these limestones/marbles are thickly bedded (1 to 3 m) and light grey, and in cliff faces weather to a white or creamy colour. These limestones are classified as micrites. They are interpreted to belong to the Jumasha Formation that is anomalously thick at Antamina as a result of structural thickening by thrust faulting.

At the head of the Antamina valley there are interbedded (2 to 3 m beds) micritic and stromatolitic limestones.

In the anticline axis on the western side of the valley dark grey to black limestones are both exposed and intersected in drill core. These have wavy bedding on a centimetric scale (bioturbated or slumped), are shelly and typically have bands of black chert nodules, and belongs to the Pariatambo Formation.

The limestones exposed in the anticline on the eastern side of the valley have a light grey core, followed by a unit of black limestone with thin grey beds, then a light grey micritic limestone. This limestone is distinct from the overlying (overthrust) beds which are typical of the Jumasha Formation.

The Jumasha Formation limestone is susceptible to karst weathering. Although no karst features are evident at surface in the immediate vicinity of the Antamina deposit, they are found in surrounding areas, while underground, cavities with high water flow (karst or fault zones) were encountered in diamond drilling in the Laberinto and Valley-South Taco areas.

Breccia

Hydrothermal breccia, lacking juvenile components and therefore probably classifiable as phreatic, is widespread and an important ore host in what was originally termed the brown garnet skarn zone. It can now be concluded that virtually all of the breccia lacks a magmatic or juvenile component.

Hydrothermal breccia cuts all types of skarn, including wollastonite varieties, but is particularly common at the endoskarn-exoskarn contact, (i.e., the original margins of the stock), and along features of suspected structural weakness within the deposit (e.g. joints, faults, etc.).

The hydrothermal breccias are intra-mineral because they cut and contain clasts of mineralised skarn, yet themselves host replacement-style and vein mineralisation of pyrite-chalcopyrite-magnetite-sphalerite. Both the breccias and the veins in endoskarn contain a similar association of metallic minerals, although magnetite is a very minor component of veins in endoskarn.

The breccias have been subdivided into crackle, mosaic and heterolithic styles. Crackle breccia is dominated by angular fragments of the immediate host rock that do not appear to have been rotated or transported, but are cut by an irregular network of narrow breccia veins. Mosaic breccia is intermediate between crackle breccia and heterolithic breccia: it consists of angular fragments of the host rock, with some rotation and/or transport of clasts, in a matrix of finely comminuted material with or without sulphide grains. Heterolithic breccia is commonly matrix-dominated containing angular to subrounded fragments of all of the rocks and minerals it cuts, as well as clasts of sulphides, magnetite, and quartz, which appear to be derived from veins and replacement selvages restricted to the breccias. The breccia matrix ranges from massive to laminated, and the clasts range from randomly oriented to locally shingled or imbricated.

Heterolithic and mosaic breccias generally contain above average Cu and Ag ore-grades, and locally carry ore-grades of Mo and/or Zn inherited from the wall rocks. Breccias may also locally contain galena.

Irregular zones of disaggregated skarn, distinct from breccia, occur in green and brown exoskarns around the margins of the deposit and appear to be stratigraphically controlled in many places.

Retrograde Alteration of Skarn

Two main variants of retrograde skarn alteration are recognised: i). chlorite-rich vein selvages in endoskarn; and ii). alteration of the intergranular matrix of indeterminate skarn to pale-green clay. The matrix of hydrothermal breccia had been considered to be altered to olive-brown-green clay, but no clay minerals were detected in it by preliminary laboratory analyses.

Retrograde alteration of endoskarn is complex, and ranges from epidote associated with chalcopyrite-pyrite blebs and veinlets that have white selvages, to chlorite associated with chalcopyrite-pyrite blebs and veinlets that have white selvages, to chlorite associated with pyrite-chalcopyrite (±magnetite) veins with crackle and mosaic breccia.

Retrograde alteration does not affect the exoskarn.

Retrograde alteration occurs in much of the endoskarn, as well as in some of the indeterminate skarns, but is only very locally pervasive. Redwood (1999) noted: “Where pervasive it [retrograde alteration] was logged as chlorite skarn and makes up less than 4% of the deposit”. While it is true that retrograde alteration is only very locally pervasive, almost all of what was originally logged as chlorite skarn is now recognised as breccia. This statement is misleading because it implies that retrograde alteration is insignificant, whereas, in fact, retrograde alteration is widespread and commonly associated with mineralisation, but is limited to structural zones where fluid flow was possible. Volumetrically only a small portion of the Antamina skarn contains retrograde alteration.

Structure

Structure is the main control on both intrusion and skarn alteration at Antamina (Fig. 4). The interpreted structural history of the deposit is summarised as follows:

The main deformational period is thought to be Incaian (ca. 41 Ma), although the district has also potentially been subjected to three later compressive events at 19 Ma,

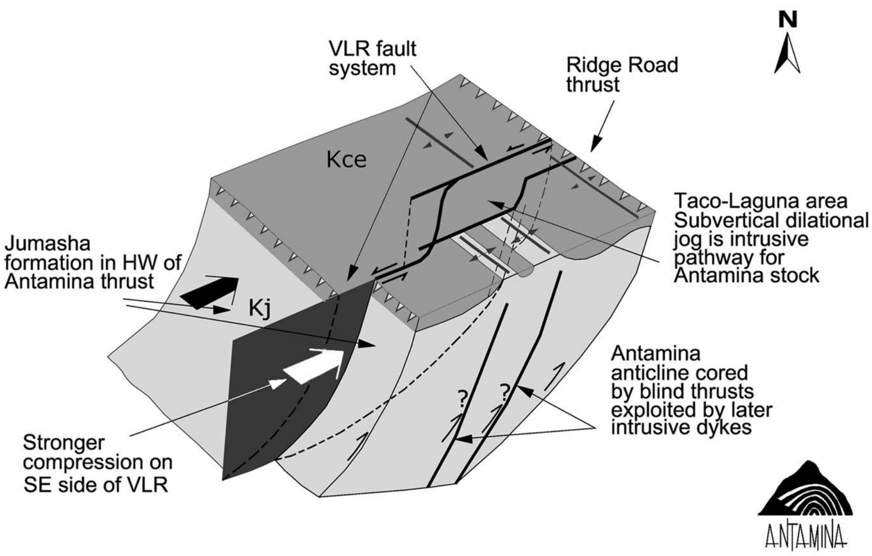

Figure 7: ***Schematic Diagram of VLR Fault During Compression***

12 Ma and 6 Ma, that are noted regionally and are termed Quechua 1, 2, and 3 (Q1, Q2, and Q3) respectively (McCuaig 2003).

At the mine scale it is difficult to differentiate the effects of any Q1 or Q2 compression and distinguish these from the earlier Incaian thrusting. Thrusting produced by this series of deformational events has resulted in a repeated limestone stratigraphy.

The thrust sequence developed during the Late Eocene, Incaic 2 phase (ca 40-41 Ma) is northeast verging. The Antamina deposit is situated within a localised thrust tongue formed by at least six flat-lying thrust sheets. This tongue is 3 km wide by 3 km long, although it may have had a greater original extent. The thrust sequence is an imbricate stack, which has resulted in a super thickening of the favourable host rocks (Jumasha) in the area.

A NE-SW striking longitudinal fault (the VLR fault of Love *et al.,* in review) is the oldest structure in the mine area. This structure initially underwent compression (Fig. 7). During subsequent extension it controlled part of the intrusion and the Antamina valley (Fig. 8) where it is exposed below a later thrust at the head of the valley.

Temporally, the Antamina stock was emplaced between the Q2 and Q3 compressive events. The final phase of Q3 compression is noted in the mine, particularly in the Oscarina area, where it is represented by moderately to shallow-dipping thrusts postdating all alteration and mineralisation.

Very localised extension occurred on the southeastern side of the present day Antamina valley, accommodated by listric faulting and by strike-slip movement along the main NE-SW longitudinal fault. This minor extensional phase may be correlated regionally with the Quechua 2 phase. The Antamina intrusions are interpreted to have been controlled by the listric faults as they are seen to occupy postulated fault planes in the limestone above the deposit. Within the deposit no obvious sign of these faults remain as their loci are now completely obliterated by intrusion and skarn.

At the margins of the deposit in Usu Pallares and Fortuna, thin intrusive sheets are apparently controlled by thrust ramps.

Post-mineral high angle fault movement appears to have occurred on the southeastern contact of the skarn on the southeast side of the valley, although neither significant displacement nor cut-off of the skarn is apparent. The postulated faulting is considered to be the result of slip caused by ductility contrast at the skarn/marble contact.

Within the skarn and intrusions there are zones of brittle breakage and slickenside surfaces, although no significant post-mineral fault displacements have been identified.

Additional detail on the structure of the Antamina deposit and its environs is available in a report by L. Hathaway (1997, CMA internal memorandum).

Mineralisation / Metal Zonation

The Antamina orebody has proven to be consistently well mineralised and predictable both in terms of grade and metal zoning. Very little of the skarn lithology comprising the Antamina deposit is unmineralised.

As with the skarn silicate mineralogy, Antamina is horizontally zoned with respect to major metal components. This lateral zoning is clearly related to the orientation of the intrusive and limestone contacts and continues throughout the nearly one kilometre of vertical range of the deposit explored to date.

Metal zonation is quite distinctive within the deposit. Copper is relatively evenly distributed from endoskarn to the limestone contact (Fig. 9). Zinc and bismuth tend to occur within 70 m of the contact of green garnet skarn with limestone/marble/hornfels (Figs. 9 & 10). Molybdenite is mainly confined to the intrusive core and surrounding endoskarn. Silver is present in any of the skarn lithologies. Lead is generally located in green garnet exoskarn, diopside exoskarn, and hornfels. Cobalt is usually associated with sphalerite mineralisation. However veins and blebs of any

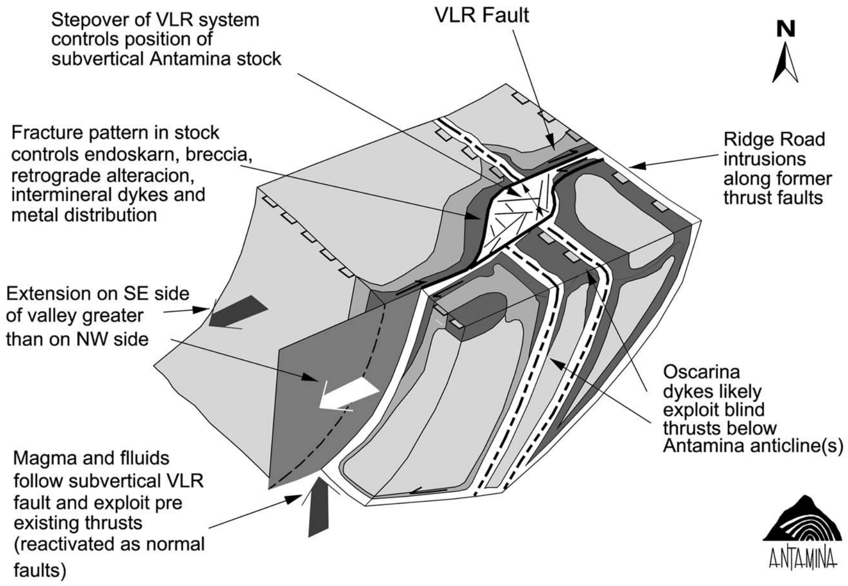

Figure 8: ***Schematic Diagram of VLR Fault During Extension***

Figures 9 & 10 Colour Insert

BLANK BACK OF COLOUR INSERT

mineral can be found as rare occurrences in any rock type at Antamina. Peripheral to the main orebody there are a number of higher grade zones with veins and/or manto type mineralisation which are generally high in lead, zinc and silver, but lack copper or molybdenite. A number of these have seen limited artisanal mining of the high grade silver and lead.

The predominate copper sulphide mineral is chalcopyrite. Approximately eight percent of the copper mineralisation is present as bornite forming a zone that is generally associated with wollastonite at the south end of the deposit. Zinc occurs as the sulphide mineral sphalerite. Silver is normally associated with chalcopyrite, although it also occurs with galena, bismuth sulphosalts and tennantite. Molybdenum exists as the sulphide mineral molybdenite.

The most common bismuth minerals include bismuthinite, cosalite, whittichenite, cuprobismutite, aikinite and kobellite.

There is little in the way of an oxidation cap and supergene enrichment. This is due to the recent glaciation of the deposit, the wet climate and the lack of significant pyrite to create acid leaching.

Deposit Formation

The following is a summary of the formation of the Antamina deposit based on observations and deductions made by the local mine geology staff. It is, no doubt, a simplification of the deposit which will be refined as further information is gathered and analysed.

Deposition of the Late Cretaceous limestone units that host the Antamina deposit was followed by thrusting of the sedimentary pile to form the Andes mountains. During this event the complex structural geometry of the Antamina valley was developed, influenced by a basement high and thrust faulting. The subsequent period of extension was accompanied by a complex series of intrusions that were emplaced approximately 10 million years ago to produce a thermal metamorphic hornfels aureole in the surrounding country rocks. The overall result of the hornfelsing was the formation of an impervious aquaclude cap over the area. Wollastonite also formed in the limestone units within the aureole, resulting in a 10% volume loss contributing to the formation of the aquaclude cap. Weak porphyry style Mo-Cu mineralisation appears to have been associated with these intrusions.

Subsequently, but probably closely related in time, a large pulse of hydrothermal fluid, emanating from a deeper distal source flowed up along the intrusion-country rock and intrusion-intrusion contacts, and along planes of structural weakness. This conclusion is deduced from the following observations: i). the fluids were obviously not in equilibrium with the intrusions present within the current deposit; and ii). the unusual coincident combination of significant zinc and copper mineralisation - usually zinc skarns are distal from, and copper skarns proximal to, the fluid source. In addition, the significant amounts of metal present in the Antamina deposit could not have been generated from the volume of intrusion present in the Antamina valley.

The aquaclude cap prevented the fluids from flowing outward from the intrusive complex into the surrounding country rocks in significant volumes and being dissipated. Hence, the formation of significant volumes of endoskarn at Antamina in comparison with most skarn deposits. Where fluids could escape along planes of structural weakness, mineralisation of limited extent formed. These historically mined deposits are "fluid leakage" features containing mineralisation up to kilometres away from the main orebody. The main orebody does, however, exhibit a classic hydrothermal metal zonation, with distal lead and arsenic, and proximal copper. No doubt the fluid chemistry evolved over time, or as multiple fluid pulses with varying fluid chemistries, producing different minerals. The bornite-wollastonite zone can be related to differences in either host rock composition or fluid chemistry.

A breccia event was initiated by either continued uplift of the Andes, or by over-pressuring of the system. This resulted in the collapse of the hydrothermal system, and the enrichment of sulphide minerals and magnetite in a series of breccia pipes formed along planes of structural weakness within the deposit. The physical separation of silicate and sulphide minerals due to density differences, upgraded the Cu values within these pipes.

The rapid collapse of the hydrothermal system precluded the formation of extensive retrograde alteration within the deposit. The last evidence of the hydrothermal system are veins of various mineralogies, usually sulphosalts, with elevated levels of arsenic, silver, lead and zinc, which crosscut the breccias and other mineralised zones within the deposit.

Continued uplift of the Andes and recent glaciations exposed the deposit at surface.

Ore Types

Currently seven ore types are recognised and two sub-types (see Table 1). These are based on metallurgical tests and production experience in the concentrator.

The purpose of these various ore types is to enhance metallurgical processing and recovery, thereby enhancing the total revenue of the deposit.

These ore types are complex and driven by a number of factors that need to be considered. The first classification separates copper only from copper/zinc ores. One of the most important classification factors in both Cu and Cu/Zn ores is Bi level. This level is important, as Bi reporting in copper concentrate can be a penalty at certain grades and is reflected in the concentrate sales contracts. Hence, the use of a Bi recovery circuit in high Bi ores to produce copper concentrate that will not incur a Bi penalty and a by-product Pb-Bi-Ag concentrate. In current plant design the Bi circuit is a dual purpose circuit which either recovers the Bi or Mo. The reason is that generally when Mo is elevated the Bi is low. Another classification is required to identify ores containing sufficient bornite to produce a separate "bornite concentrate" which is significantly different from the typical chalcopyrite "copper concentrate".

Four major categories of concentrate are produced, namely: i). chalcopyrite and bornite copper, ii). sphalerite zinc, iii). molybdenum, and , iv). a lead-silver-bismuth concentrate. The copper and zinc concentrates are shipped to the port via the pipeline, the molybdenum and lead-silver-bismuth concentrates are bagged at site and shipped by truck to the port facilities.

Resource Estimate

An interiem resource model study was completed in November 2003, which explored various modeling methodologies and elements. This interim resource model study will be used as the basis for the ongoing drill programs and refined resource model estimations scheduled in 2004 and 2005. The interim resource model is complex with 12 model elements, incorporating new drilling data, enhanced knowledge of metallurgical processing, an improved knowledge of geology and lithology, and improved interpolation techniques. There is a confidence increase in the geologic model compared to the 2000 Resource Model and the 1997 Feasibility Resource Model.

The current August 2000 resource model blocks were classified as Measured, Indicated, and Inferred (identified) Resources using the *CIM Standards on Mineral Resources and Reserves, Definitions and Guidelines* dated August 20, 2000. These standards are very similar to those of the *Joint Ore Reserve Committee (JORC)* of the *Australian Institution of Mining and Metallurgy,* and the resource classification is compatible with the 1999 JORC Code.

Classification criteria using the number of holes and the spacing of the holes to a block were developed using 90 percent confidence levels for tonnage, grade, and contained metal. The confidence levels for copper and zinc are different based on the natural distribution of the two metals.

The resource at Antamina as estimated in 2000 and existed at mine startup, is shown in Table 2.

Acknowledgments

The authors gratefully acknowledge all geologists who have previously and currently contributed to the geologic body of knowledge of the Antamina Deposit. Without their work this paper would not be possible. Additionally the authors acknowledge Compañía Minera Antamina S.A. management who permitted the publication of this general reference paper on what is truly an interesting and challenging world class deposit.

CODE	ORE TYPE	Cu %	Zn %	Bi ppm	Remarks
M1	Cu, Low Bi	≥ 0.5	< 0.5	< 20	High Grade > $12.30 NSR
M2	Cu, High Bi	≥ 0.5	< 0.5	20 - 115	Low Grade ≥ $8.60 < $12.30 NSR
M2A	Cu, Very High Bi	≥ 0.5	< 0.5	≥ 115	Marginal Grade ≥ $6.10 < $8.60 NSR
M3	Cu - Zn, Low Bi	≥ 0.5	≥ 0.5	< 20	
M4	Cu - Zn, High Bi	≥ 0.5	≥ 0.5	20 - 115	
M4A	Cu - Zn, Very High Bi	≥ 0.5	≥ 0.5	≥ 115	
M5	Bornite, Low Zinc	≥ 0.5	< 0.5	(*NA)	(*NA) - Not Applicable, Bornite ores
M6	Bornite, High Zinc	≥ 0.5	≥ 0.5	(*NA)	contain wittichenite intergrowths

Table 1: ***Antamina Deposit Ore Type Classification Criteria***

Resource Class	Tonnage (Mt)	Metal Grades				
		Cu (%)	Zn (%)	Ag (g/t)	Mo (%)	Bi (ppm)
Measured	358.30	1.25	1.01	13.50	0.03	60.80
Indicated	777.40	0.81	0.68	9.50	0.02	68.30
Sub-total	**1135.70**	**0.95**	**0.78**	**10.80**	**0.03**	**65.90**
Inferred	1787.00	0.30	0.26	4.60	0.01	39.50
TOTAL	**2922.70**	**0.55**	**0.46**	**7.00**	**0.02**	**49.80**

Table 2: ***Antamina Deposit Geologic Resources, August 2000 Resource Model (Zero Cutoff)***

References

Antamina Mine Geology Logging Manual and Coding Instructions, Version 1.53, November 3, 2000.

Hathway, L. H., 1997 - Geological surface mapping and structural interpretation at Antamina, Peru: *Internal report for Compañía Minera Antamina S.A.*, 35p.

Love D. A., Clark, A. H., and Glover, K. J., 2004 - The Antamina deposit, Ancash, Peru: The stratigraphic and structural setting of a giant copper-zinc skarn: *Economic Geology,* v. 99, pp. 887-916.

McKee, E. H., Noble, D. C., Scherkenbach, D. A., Drexler, J. W., Mendoza, J., and Eyzaguirre, V. R., 1979, - Age of porphyry intrusion, potassic alteration, and related Cu-Zn skarn mineralization, Antamina district, northern Peru: *Economic Geology,* v. 74, pp. 928-930.

Pacheco A. M., 1997 - Intrusivo en el Skarn Antamina: *Internal report for Compañía Minera Antamina S.A.,* 26p.

Redwood, D. D., 1999 - The Geology of the Antamina Copper-Zinc Skarn Deposit, Peru: *The Gangue, Geological Association of Canada Mineral Deposits Division Newsletter,* Issue 60, pp. 1-7.