GEOLOGY, GRADE DISTRIBUTION, AND METAL RATIOS
AT THE AMARO GOLD-COPPER PORPHYRY DEPOSIT,
MINAS CONGA DISTRICT, CAJAMARCA PROVINCE, PERU

By

Nirio Mendoza

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“Ama Sua” (don’t rob)

“Ama Jella” (don’t be lazy)

“Ama Llula” (don’t lie)"

(Inca’s Empire strategic foundation)

This work is dedicated:

To my parents, who never figured out their son’s wingspan.

To my wonderful family: Merwin, Jaqueline, who embarked with me on the most important project of my professional life.

For them, all my gratitude and love.

In special dedication to my little girl, Hazel,

A new inhabitant in our amazing and Fragile home, the Earth.
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Geology, grade distribution, and metal ratios at the

Amaro gold-copper porphyry deposit, Minas Conga district,

Cajamarca Province, Perú

Nirio Mendoza and Eric Seedorff

Institute for Mineral Resources and Department of Geosciences

University of Arizona

1040 East Fourth Street, Tucson, Arizona USA 85721-0077
Abstract

The Amaro deposit is one of a cluster of Miocene gold-rich porphyry deposits in the Minas Conga district of northern Peru. The deposits are located 10 km east-northeast of the world-class epithermal gold deposits of the Yanacocha district. Amaro, after Chailhuagón and Perol, is the third largest deposit discovered in the district to date. Using metal prices of $425/oz Au and $1.10/lb Cu, Amaro has 0.97 M contained oz Au and 207 M contained lb Cu at average grades of 0.4 ppm Au and 0.13% Cu,. The Amaro deposit is a gold-rich porphyry system with one of the highest Au:Cu ratios at the Minas Conga district located in northern Peru. New U-Pb dates The hydrothermal system is associated with the emplacement of a Middle Miocene (15.7 to 15.5 Ma) columnar stock of granodiorite to tonalite. Mineralization is hosted by carbonate rocks and early hornblende diorite.

The highest Au-Cu grades, with vertical extension and still open at depth, are related to oxidized hydrous melts that generated the main productive porphyry and related intramineral granodiorite intrusions. Both intrusions have less than 62% SiO$_2$ and are similar to those reported at other gold-rich porphyry systems throughout the world. Hypogene Au and Cu mineralization developed as part of potassic alteration assemblages that include abundant quartz stockwork veins (up to 70% in the core of the system) that contain magnetite, secondary biotite, and chalcopyrite-pyrite ± bornite. Microscopic studies revealed fine inclusions of native gold, mainly within or bordering chalcopyrite and bornite.

Although the Amaro deposit is part of the NW trending Amaro-Lindero corridor, it is controlled locally by the east-west and north-south structures. Porphyry clusters in
the region are emplaced within the northwest trending Cu-Au metallogenic belt in the Miocene Andean arc. The folding, thrust faulting, and tensional structures in the region are related to clockwise evolution of major stress that is coincident with periods of peak Tertiary magmatism associated with orogenic episodes and high plate convergence rates.

**Introduction**

Metal zoning, i.e., the zoning of metal abundances and of metal ratios, is commonly used to explore for porphyry deposits (Lowell, 1991; Garwin, 2002; Sillitoe and Thompson, 2006). In principle, metal zoning patterns can provide insight into system-scale geologic and geochemical processes, as well as potential differences in initial concentrations of various metals in different classes and subclasses of porphyry deposits; nonetheless, there are relatively few, well documented examples of metal zoning for a suite of ore metals in porphyry systems (Seedorff et al., 2005).

Threshold values of gold content or copper : gold ratios have been used to define gold-rich porphyry deposits (Sillitoe, 1979, 2000; Kesler et al., 2002; Kirkham and Sinclair, 1995). Although gold-rich porphyry deposits commonly are viewed as a distinct entity, Seedorff et al. (2005) showed that gold-rich deposits are petrologically diverse, including two alkaline subclasses and one subalkaline subclass of the porphyry copper class of deposits, and as well as the porphyry gold class, and each subclass has distinctive characteristics.

Metal zoning is related to the differences in mineral solubility and concentrations. In principle, the least soluble mineral in a particular solution will be deposited first near the source of the metal-carrying solution, followed in turn by minerals with higher solubility (Barnes, 1975; Hemley and Hunt, 1992). In detail, however, both metal zoning
and mineral zoning are final, time-integrated products of the time-space evolution of geological systems. In general, such systems are complex, with the potential both for multiple periods of introductions of fluid (e.g., exsolution of magmatic-hydrothermal fluids from multiple intrusions), as well as multiple types of fluid sources (e.g., magmatic-hydrothermal and external).

Metal zoning is directly related to the mineral zoning of ore deposits. As a result, interpretation of mineral zoning and metal zoning are inherently linked. If the potential geologic complications to interpretation can be adequately managed, then metal zoning patterns might provide insight into potential differences in initial concentrations of various metals in different classes and subclasses of porphyry deposits (e.g., Seedorff et al., 2005). Nonetheless, published cross sections and maps showing the relative distribution of metals, especially in gold-rich porphyry systems, still are relatively uncommon, limiting understanding of metal precipitation and metal zoning.

The Amaro deposit, located in the Minas Conga in northern Peru, is a relatively simple system geologically, thereby providing an excellent opportunity to examine metal zoning in a gold-rich porphyry copper deposit. In this study, we provide the first description of the Amaro deposit and constrain its age with three U-Pb dates. We present detailed geologic cross sections based on detailed surface mapping and core logging that show rock types and various alteration-mineralization features, including density of stockwork veinlets and distribution of sulfide minerals and magnetite. We then use geochemical assays from drill holes to define the distribution of metals and metal zoning patterns.
Location

The Amaro deposit is a middle Miocene porphyry system located in northern Peru, approximately ~630 km north of Lima (Fig. 1). Amaro is located in the La Encañada jurisdiction, 70 km north of the city of Cajamarca.

Amaro, together with the Perol and Chailhuagón deposits and other prospects, is assigned to the Minas Conga district of northern Peru (e.g., Llosa et al., 2000; Gustafson et al., 2004). Amaro is situated at the northern end of the Minas Conga district, within a north-south alignment of porphyry clusters in the district, 5 km north-northwest of the Perol deposit and ~20 km east-northeast of the epithermal Yanacocha district (Fig. 2).

Regional Geology

The geology of the Cajamarca Province consists of strongly folded and thrust faulted sedimentary units and lesser extrusive and intrusive rocks (Figs. 2-4). The deformation and magmatism are related to the Andean tectonic period (Mégard, 1984) and composed of two major phases: 1) a Late Triassic to Late Cretaceous, fundamentally extensional, phase that was characterized by the accumulation of marine sequences, including products of Mariana-type subduction, and 2) an interval from the Late Cretaceous to the present characterized by an absence of local sedimentation during successive contractional events during Andean-type subduction, as well as associated volcanoplutonic activity and massive orogenic uplift (Benavides-Caceres, 1999).

In the Minas Conga district, Mesozoic (Valanginian to Cenomanian) sedimentary units range from silty shale in the lower part, to platform limestone in the middle part, and interbedded silty limestone and shale in the upper part (Llosa and et al., 2000;
Benavides-Caceres, 1999). Within the southern and northern parts of the district and restricted areas to the west-southwest, however, sandstone-bearing sequences also have been observed. These successions, assigned to the Lower Cretaceous Goyllarisquisga Group, indicate tectonic quiescence with some regressions and short transgressions (Benavides-Caceres, 1999). The Goyllarisquisga Group consists of quartzite of the Chimu Formation, carbonaceous silty sandstone and shale of the Santa Formation, the Carhuaz Shale, and the Farrat sandstone. Restricted and calc-silicated remnants of the Pariatambo Formation have been reported at the Perol porphyry (Llosa et. al., 2000; Conga Team, 2005). Above these units lies the extensive Late Cretaceous Yumagual Limestone, which has minor shale intercalations. The Yumagual Limestone is the only marine sedimentary basement unit exposed around the Amaro project. Restricted areas of the latest Cretaceous Cajamarca Formation and Celendin Formation have been reported north and south of the Minas Conga district (Reyes, 1980; Benavides, 1999).

Numerous Tertiary igneous rocks are present in the region (Laughlin et al., 1968). The oldest rocks are Eocene dioritic intrusions, which correspond to the Picota diorite dated at 43.6±3.7 to 42.03 Ma (Llosa et. al., 2000; T. B. Thompson, written comm., 2002) the Michiquillay diorite, dated at 46.4±1.8 Ma (Davies and Williams, 2005), another diorite stock at San Cirilo, for which Pinto (2006) reported a date of 36.4±0.9 Ma. Several of these Eocene dioritic intrusions, including the ones at Picota and San Cirilo, are associated with polymetallic and skarn mineralization.

Middle Miocene granodiorite, quartz diorite, and diorite intrusions that range in age from ~20-15 Ma produced a series of porphyry systems, including Michiquillay, El
Galeno, Perol, Chailhuagón, and Amaro (Laughlin et al., 1968; Llosa et al. (1996); Noble, 2002; Davies and Williams, 2005; this study).

In the Minas Conga-Yanacocha region, silicic to intermediate volcanic rocks of the Yanacocha volcanic complex unconformably overlie the Mesozoic sedimentary rocks. These units are predominantly rhyolitic to rhyodacitic pyroclastic rocks and include thick units of rhyolitic ash-flow tuff (Noble et al., 1990). Historically, these rocks have been assigned to the Calipuy Group which in turn is subdivided into the Llama, Porculla, and Huambos Formations (Reyes, 1980; Cobbing et al. 1981; Wilson, 1984). Noble et al. (1990), however, showed that obtained an age of 35.4 ± 1.2 Ma for the top of the type Calipuy Group, but Longo (2005) has established that the Yanacocha volcanic complex is considerably younger, with ages ranging between 19.5 to 8.4 Ma.

Younger volcanic rocks also are present in the Minas Conga district, and these are assigned to the Fraylones Formation. Rocks of the Fraylones Formation are described as andesitic to dacitic pyroclastic rocks (Llosa and et al., 2000) And are considered to be younger than the Quechua II orogenic event, i.e., <9 Ma (Noble and McKee, 1999).

**Mineral Deposits of the Cajamarca Area**

The Minas Conga district includes three porphyry systems, Chailhuagón, Perol, and Amaro, in which mineralization crops out at the surface. Other systems have been discovered at Lindero, Huaylamachay, Morocha, Chasu, and Gentiles. Finally, small volcanic vents that contain clasts of stockwork-veined porphyry derived from a deeper hypabyssal source (e.g., Pampachica and Atocha) constitute additional porphyry systems in the Minas Conga district.
Other mineralized systems occur in the vicinity of the Minas Conga district, such as the Galeno, Michiquillay, and Cerro Corona porphyry systems, the high-sulfidation epithermal systems of Yanacocha, Sipán, and Tantahuatay, and the polymetallic systems in the Hualgayoc district or San Cirilo complex (Figs. 2, 4).

These deposits occur within a northwest trending belt of deposits, the Miocene Cajamarca-Huaraz metallogenic belt (Noble and McKee, 1999; Sillitoe, 2008), the timing of which has been attributed to initiation of flat-slab subduction as the Nazca Ridge descended beneath the South America plate (e.g., Rosenbaum et al., 2005). The deposits in the belt contain a total of ~86 million contained oz Au in production plus reserves, principally in the Yanacocha district (Sillitoe and Perello, 2005; Sillitoe, 2008). The deposits in the Cajamarca region appear to be aligned along an arc-transverse structural zone known as the northeast-striking Chicama-Yanacocha structural zone (Quiroz, 1997), which is at high angles to the main Cajamarca-Huaraz belt (Fig. 2).

**Exploration History of Amaro**

Mining in the Cajamarca area began in the pre-Inca epoch, especially in Yanacocha as a source of mercury and in the Hualgayoc district for base metals. A smelter was built in the colonial era by the Spanish in Hualgayoc, and additional small smelters were built in the region during the 1900’s, such as in the village of Punre.

The discovery histories of porphyry systems in the Minas Conga district and of the huge epithermal gold systems in the Yanacocha district are linked. The discovery of gold in the Yanacocha district was announced in 1986, and this was followed by enactment of numerous government laws to attract international investment, leading to the 1990s exploration boom in Peru. Companies such as CEDIMIN, a subsidiary of the
Bureau de Researches Géologiques et Minières (BRGM), a French government-owned company, started working in the Minas Conga district in 1992. CEDIMIN conducted aggressive stream sediment sampling and geologic exploration programs (Llosa et al., 2000). CEDIMIN reported the discovery of the Chailhuagón and Perol porphyry deposits in 1998 and named the Amaro porphyry prospect in an internal annual exploration report for 1998-1999. Amaro was recognized initially by district exploration mapping then was further defined by geochemical sampling and geochemical surveys (Llosa et al. 2000), leading CEDIMIN to drill eight exploratory diamond drill holes. The best drill intercept reported was in hole Q-2, which contained 36 m that averaged 1.52 ppm Au and 0.44% Cu. CEDIMIN considered the deposit sub-economic.

CEDIMIN’s properties in the Cajamarca region were sold to Minera Yanacocha SRL at the end of 2001. Minera Yanacocha initiated a new stage of exploration that included re-mapping, re-sampling, and reinterpreting geophysical anomalies in 2004, which involved Mendoza. After these investigations, 13 diamond drill holes were completed, several of which intercepted high grade Au-Cu porphyry mineralization that remained open at depth. Between 2005 and 2006, the Yanacocha Mines Geology Group continued with an in-fill drilling program, defining a viable resource.

**Ore Reserves and Mineral Resources**

A total of 38 holes were drilled in the Amaro project starting with CEDIMIN until the start of the in-fill drilling program concluded by the Yanacocha group. Newmont’s combined ore resources for the Amaro deposits, using prices of $425/oz Au and $1.10/lb Cu, is 968,390 contained oz Au and 207,284 k lb Cu with average grades of 0.4 ppm Au and 0.13% Cu (Anonymous, 2005). The resource at Amaro adds to the main reserve in
the Minas Conga district at Chailhuagón and Perol, two separate but adjacent porphyry deposits in the district. Newmont’s combined ore reserves for the latter two deposits is 8.71M contained oz Au at average grades of 0.8 ppm Au and 1.01 million tons of contained copper at 0.3% Cu.

Methods

The area described in this report covers 2.4 km x 1.7 km and ranges in elevation from 3100 to 4050 m. The first stage of geologic mapping of the deposit by Yanacocha was conducted by Carl Schnell and Jerry Mohling in 2004, afterward joined by Mendoza.

Cross sections

After a quick field review to compile the surface maps and detailed logging and re-logging, two set of cross sections were constructed for this study: N30°E looking to the NW (section 3) and S25°E looking to the NE (section 9). Each of these sections has a series of overlays for geology (rock type and structure), alteration, sulfide distribution, magnetite distribution, density of veinlets, sulfide distribution, mineral zoning, grade distribution, and metal ratios.

Geochronologic study

The uranium-lead (U-Pb) method was applied to determine ages for zircon grains recovered from three igneous units from Amaro. These U-Pb isotopic studies were conducted at Arizona Geochronology Center at the University of Arizona. The purpose was to determine the age of crystallization of the productive intrusions and the overlapping volcanic unit. At least two analyses were performed on each zircon grain:
one in the center (core) and one on the rim (edge) of the crystals. The goal was to contrast the age of rim, which should yield the age of magma crystallization with that of the core, which under some circumstances could yield information about the age of basement rocks incorporated into the magma. Additional information is contained in the appendices. The zircons recovered and analyzed came from the following three samples:

- Drill hole MCA-013, from 506 to 508 m, and described as the main productive intrusion that exhibits potassic alteration.
- Drill hole MCA-009, from 581.5 to 590.5 m, and described as an intra-mineral intrusion.
- 10_LHR, weak chloritized to fresh rock, from an outcrop located south of the Amaro project (UTM-WGS84: 790 282; 9 240 103; 3929 m).

Whole-rock geochemical analysis

Three samples were analyzed for whole-rock geochemistry with the purpose of having representative major- and trace-element analyses of the same rocks as dated by the U-Pb method. The analyses of MCA-13 and 10-LHR were from exactly the same intervals as those sampled for U-Pb geochronology, whereas the analyzed sample of the intramineral unit is from drill hole MCA-21 (480.50 m). The samples were submitted to Skyline Laboratories for analysis. The WR-1 analytical package was used to obtain major element analyses using lithium metaborate/tetraborate fusion and inductively coupled plasma (ICP)/ optical emissions spectroscopy (OES) analyses. The WR-2 analytical package was used to obtain data for trace elements using lithium metaborate/tetraborate fusion and ICP/OES analyses. The results are given in Tables 1 and 2.
Petrographic studies

A total of 12 samples from typical units and intervals were examined by standard techniques using a petrographic microscope. The intention was to describe the microscopic fabric of the rock, to define the composition and the alteration of the matrices, and to identify the opaque minerals.

Rock Types and Geochronologic Results

Yumagual Limestone

The predominant basement unit at the Amaro project is the Late Cretaceous Yumagual Limestone. This limestone is generally massive but contains with local thin beds. The unit crops out in the southeastern corner of the mapped area, nearly as a dip-slope of shallow to moderate angles (15 to 30°). A second area of limestone outcrop occurs in the north-central portion of the map. Short intervals and blocks of limestone, converted to marble or skarn and engulfed by intrusions, have been logged in drill holes (Figs. 5 and 6).

Early porphyritic hornblende diorite

The early porphyritic hornblende diorite (map unit EHD) is characterized by a variable texture, ranging from a uniform, fine grained (sugar sized crystals) intrusive to seriate textured porphyry, with partially flow banded or aligned hornblendes (Fig. 7). The unit contains phenocrysts of zoned plagioclase, hornblende, and biotite, as well as >1% quartz, set in a groundmass of microcrystalline feldspar, quartz, and biotite. Crystals typically range from 1 to 5 mm in length, with plagioclase occasionally >5 mm
(Figs. 8 and 9). This unit, together with the Yamagual Limestone, is interpreted as a major wall rock of the porphyry system because of the increase in alteration toward the main mineralized intrusion. The unit is elongate east-west in plan view. A $^{40}$Ar/$^{39}$Ar age on hornblende of 17.30 Ma is reported for this unit (T. B. Thompson, written comm., 2002).

*Amaro Mirador intrusion*

This dioritic stock contains plagioclase, hornblende, and biotite with trace to 1% quartz eyes and is characterized by a seriate porphyritic texture. This unit is located north-northeast of the Amaro prospect and exhibits a clear east-west, fault-controlled contact with the Yumagual Limestone (Fig. 10). This unit is mostly fresh to weak chloritized but contains silica-alunite ribs.

*Main productive granodiorite*

The main productive granodiorite (map unit MPG) contains phenocrysts of plagioclase (3-5 mm), biotite (up to 8 mm), hornblende, and 3-5% quartz eyes (3-5 mm) set in a microcrystalline groundmass. This unit is difficult to distinguish from the intraminerai unit solely based on appearance in hand specimen, but contacts with other units can be recognized on the basis of the relative intensity of potassic alteration and abundance of quartz veins (Figs. 11-17). Re-logging and field observations made during this study indicate that the main productive granodiorite does not crop out at the present surface. This unit remains open at depth, with an overall columnar. A new U-Pb date for this unit (see below) yields an age of 15.7 ± 0.5 Ma.
*Intra-mineral granodiorite porphyry*

The intra-mineral granodiorite porphyry (map unit IPG) has phenocrysts of plagioclase (3-5 mm), biotite (up to 8 mm), hornblende, and 3-5% rounded quartz eyes phenocrysts (3-5mm) set in a microcrystalline groundmass of quartz and K-feldspar. The intra-mineral granodiorite porphyry extensively truncates quartz veins at contacts with the main productive porphyry unit, generally with chilled contacts and sharp decreases in grade and intensity of alteration (Figs. 18 and 19). A new U-Pb date for this unit (see below) yields an age of 15.5 ± 0.3 Ma.

*Fragmental andesite*

The fragmental andesite unit is clast supported and contains subrounded to angular monolithic fragments of hornblende andesite with sparse biotite and quartz, commonly of cobble size, in a matrix of subhedral to partially broken crystals of plagioclase, hornblende, and sparse biotite and quartz. In outcrop (Fig. 20), the unit is crudely stratified (east-west strike, dip ~10°N) and apparently is interbedded with thin andesitic lava flows. Pumice and eutaxitic fabrics are absent (Fig. 21). The best outcrops extend from the southern to central part of the project area, seemingly filling topographic lows. The continuity of these exposures has been corroborated in drill holes such as MCA-001, up to 200m with progressive alteration toward the central area. Straight-walled, centimeter-scale dikes of sand-sized material, clastic dikes, commonly cut the fragmental fabric.

The genesis of the fragmental andesite is uncertain. In the absence of compelling evidence for being pyroclastic, widespread unit could be a brecciated, aa type of lava
flow or a volcanic debris flow generated by lahar processes (Fisher and Schmincke, 1984; McPhie et al., 1993; Vallance, 2000).

The age of the fragmental andesite also is in question (Fig. 22). Although this unit is mostly fresh to chloritized (i.e., altered to chlorite + pyrite), it displays weak to moderate potassic alteration in outcrop and in drill holes near or over the projection of the main productive granodiorite and has anomalous to ore-grade gold contents. In hole Q-2, the unit contains secondary biotite and magnetite in the groundmass that are accompanied by 1-2 vol% veins of magnetite and quartz-magnetite, with Au grades of 0.05 to 0.15 ppm, increasing to 0.3-0.4 ppm near contacts with the main productive granodiorite. Based on these characteristics, fragmental andesite has been considered a pre-mineral wall rock.

U-Pb dates on zircon separates from the fragmental andesite shows four groups of ages, ranging from ~135 to ~12 Ma; however, the youngest age of 12.9±0.7 Ma is the maximum age suggested for the crystallization of the rock, in which case the older ages might be zircons inherited from basement rocks. Field observations that indicate that the rock has a relative age that is older than a porphyry intrusion dated at ~15.7 Ma are inconsistent with the U-Pb isotopic age of the fragmental andesite of 12.9±0.7 Ma. Further work is required to determine the origin and age of the fragmental andesite unit.

*Hornblende needle dikes*

A distinctive unit that occurs as north-northwest striking porphyritic dikes (Fig. 23) exhibits needle-like crystals of hornblende (up to 0.5 cm) that are sometimes twinned (C. Schnell, written comm., 2005). The unit also contains euhedral plagioclase phenocrysts (1-3 mm). This unit cuts the fragmental andesite and other previous units.
Textural similarities suggest that the dikes may have fed the fragmental andesite unit. Toward the central part of the area, this unit shows moderate potassic alteration secondary biotite and magnetite, ~1 vol% magnetite-quartz veinlets, and trace sulfide. These relationships indicate that the dikes, which have not been radiometrically dates, are older than the intrusions that formed the porphyry system.

*Heterolithic breccia*

This fragmental unit (map unit HBx) is heterolithic (Fig. 24), commonly containing clasts of the main productive granodiorite cut by quartz-magnetite veins, pink K-feldspar fragments, and large unmineralized clasts of granodiorite porphyry in a rock flour matrix. This breccia truncates veins in the main productive granodiorite in holes Q-5, O-4, and M-14. In turn, this breccia might be cut locally by the latest intrusions.

This breccia was intercepted for almost 200 m near the surface in hole Q-5. Outcrops of the breccia body are located over the projection of the main productive granodiorite. The distribution of outcrops and drill hole intercepts of the unit suggest an upward-flaring geometry. Gold grades typically range from 0.1-0.2 ppm, but the density of veins and gold grades increase to as much as 0.4 to 0.6 ppm near the margins of the main productive granodiorite, partially or entirely due to the incorporation of numerous, previously mineralized fragments. In common with most other poorly cemented breccias in rock flour matrix in porphyry systems (Seedorf et al., 2005), the characteristics of this unit at Amaro suggest a phreatic breccia origin (e.g., Sillitoe, 1985), perhaps triggered by emplacement of one of the latest intrusions.

*Dacitic ash tuff*
Tuffs of dacitic composition were mapped to the north-northwestern part of the project area. This unit apparently overlies the fragmental andesite and underlies the glacial moraines. This unit probably correlates with the Peña de Leon pyroclastic rocks dated at 11.58 Ma (T. B. Thompson, written comm., 2002) located to the west of the Amaro area.

Glacial moraine

The moraine is found within the northwestern sector of the map area. It is notable for containing numerous glacially-transported and polished boulders of tuffaceous rocks that have high-sulfidation alteration (silica-alunite-pyrite). These boulders might be remnants of a lithocap to the Amaro deposit (S. J. Meldrum, written comm., 2005; C. Schnell, written comm., 2005).

Compositions of Intrusions

Samples of main productive granodiorite (MCA-013, 506 m), the intra-mineral granodiorite porphyry (MCA-021, 480.50 m), and fragmental andesite (10_LHR from outcrop) were analyzed for major-element and trace-element contents. For example, the main productive granodiorite and the intra-mineral granodiorite porphyry reported 60.19% and 61.58 % of total SiO₂ contents, respectively (Table 1). Although the samples sent for these analyses had minor secondary quartz contents (quartz veins or silicification), all samples had SiO₂ contents of less than 62%. Even though these hypabyssal rocks have sparse quartz phenocrysts and hydrous mafic minerals, akin to plutonic rocks normally classified as quartz diorite, tonalite, or granodiorite, the SiO₂ contents of the rocks from Amaro fall within the range of andesites, 57-63%, in arc...
volcanic rocks (e.g., Le Bas et al., 1986; Hildreth, 2007), rather than dacite or rhyodacite. The contents of SiO$_2$ Al$_2$O$_3$, and K$_2$O determined for Amaro also resemble those observed in porphyry gold systems (e.g., Muntean and Einaudi, 2000).

In spite of similarities in K$_2$O and Na$_2$O contents, contents of rubidium (Rb >1608 ppm) reported for the three samples are more than an order of magnitude higher than reported for otherwise similar porphyry systems, suggesting a possible suspect analysis.

**Structure**

Rose diagrams based on compilation of structural measurements in the field, interpreted air-photo lineaments, and observed geology yield three major trends: N30°W, east-west, and N10°E (see below and Fig. 30). The most notable structure in the Amaro area is the east-west striking the Mirador fault zone, which appears to crosscut the other two sets of structures. At the surface, the other structures mainly are mapped as joints, although certain dikes and intrusive contacts are oriented parallel to these directions. For example, contacts of the early hornblende diorite are oriented east-west and northwesterly. The needle hornblende dikes heterolithic breccias strike northwesterly, as does the orientation of the main productive granodiorite stock. The contact between the Mirador stock and the Cretaceous basement also is oriented east-west.

**Hydrothermal Alteration**

Surface and drill hole exposures of the deposit display vertical and lateral zoning of alteration. The most important alteration types are described below.
**Potassic**

In the center of the project, moderate to intense potassic alteration affects the various rock types, but in different proportions. Areas of potassic alteration are characterized by hummocky topography that is located in the most eroded and the topographically lowest position of the project. The alteration is typified by early disseminated and later veinlet-controlled magnetite and sulfides, in addition to biotite as disseminations of fine to coarsely crystalline biotite associated with quartz veinlets. Sulfides such as chalcopyrite-pyrite are associated at the surface with veinlet-controlled magnetite.

For the purpose of the geologic cross sections, three intensities of potassic alteration are distinguished: partial potassic (PTP), in which hornblende ± biotite phenocrysts are partially replaced by secondary biotite; biotitized potassic (PTB) in which the secondary biotite completely replaces all primary mafic phenocrysts; and the K-feldspar potassic (PTF), when there is a notable presence of K-feldspar in vein envelopes and patchy areas of the matrix. These variations are most visible in the main productive granodiorite but also in some intervals of the intra-mineral granodiorite porphyry or near the contact with the early porphyritic hornblende diorite. Alteration within the intra-mineral granodiorite porphyry is mainly of magnetite with partial secondary biotite. Some restricted overprint by chloritic or chlorite-epidote alteration over the potassic alteration is observed. At depth, the K-feldspar abundance increases; however, only small and isolated areas shows a pervasive K-feldspar potassic alteration within the early hornblendic unit. The density of quartz veinlets ranges up to 70 vol%
associated with intense potassic alteration in the core of the system. The alteration and Au-Cu contents diminish outward.

Because of magnetite association with potassic alteration, cross sections were generated to show the distribution of the total visual presence of magnetite. The presence of >3 vol% magnetite is mostly in the main productive granodiorite. In the rock containing heterolithic breccia, the estimate of magnetite abundance is up to 2 vol%, contained as clasts of previously altered rock (Fig. 24).

**Argillic**

Outcrops classified as argillic alteration are partially to completely oxidized and weathered. These areas of clay alteration are erosionally recessive and lack good outcrop. These areas lack quartz veinlets; however, some pyrite and magnetite veinlets are present immediately next to potassic alteration.

In cross section, the argillic alteration is restricted mostly to heterolithic breccia or narrow structures. Drill holes confirm that most of the area mapped as argillic at surface apparently is just restricted to 2 or 5 meters at depth and is thus of supergene origin, and there is a transition downward into unweathered primary alteration, generally intermediate argillic, potassic, and propylitic.

**Intermediate Argillic**

Intermediate argillic alteration spatially overlies or occurs within volumes of potassic alteration. The assemblage for this alteration is pervasive to patchy replacement of plagioclase and biotite by medium yellow-green to darkish brown sheet silicate minerals (illite or smectite?), ± silica, clay, chlorite, pyrite, and magnetite. Calcite,
hematite, anhydrite may also be present. In some endoskarns, anhydrite-calcite veins are surrounded by wide complex envelopes of brown sericite with occasional chalcopyrite veinlets. Therefore, some zones have elevated Au and Cu grades (S. Moore, written comm., 2004). In hole Q-5, deep oxidation with pervasive dark brown sericite affects the heterolithic breccia units.

\textit{Propylitic}

Propylitic alteration is peripheral to the potassic and argillic zones and extends to the south. The characteristic assemblage is chlorite, epidote, illite(?) associated with weaker pyrite, chalcopyrite, and magnetite. Areas with this alteration seem form topographically resistant ridges in the map area (C. Schnell, written comm., 2005). This alteration type is weakly mineralized to barren and surrounds the mineralized part of the system.

\textit{Exoskarn, calc-silicate hornfels, and endoskarn}

Diopside-epidote, chlorite, and/or garnet locally occur in endoskarn and exoskarn in the drill holes. At surface, some limited areas were mapped where endoskarn developed in the early hornblende diorite. Pyrite, traces of chalcopyrite, and occasionally bornite are observed in this alteration. Some high-grade intercepts with more than 1 ppm Au, have been reported in carbonate wall rocks (e.g., holes Q-2 and O-7). In the endoskarn, ferromagnesian mineral sites are replaced by diopside and grossular garnet.
Marble

Recrystallized limestone occurs where calcareous sedimentary rocks are present near intrusive rocks. Locally, small veins of calc-silicate minerals are occur within marble.

Vein Types and Distribution of Vein Densities

Above the main porphyry stock, an area measuring approximately 500 m x 400 m contains quartz veinlets although there are few outcrops due to erosion and unconsolidated cover (Figs. 25-34). At surface, these quartz veinlets are ubiquitous within the area of potassic alteration (C. Schnell, written comm., 2005), primarily within the early hornblende diorite and restricted areas within the fragmental andesite and heterolithic breccia body. Irregular zones of sparse quartz veinlets (commonly associated with thin magnetite veinlets) occur within the argillic altered zone (see above). In outcrop, areas with more abundant quartz veins (1 to 15%) are associated with more intense and coarsely crystalline secondary biotite. Even relatively young units, such as the needle hornblende unit, contain occasional thin magnetite veinlets with sparse sulfides. The area of magnetite veins has a slightly wider distribution than the area of quartz veins, making such magnetite veins a good exploration guide to non-outcropping porphyry systems.

In drill holes, most quartz veins are ‘A’ type of Gustafson and Hunt (1975) and Proffett (2003), but there is textural variety, including coarse quartz-magnetite, multiply-banded quartz-magnetite (some reaching thicknesses of 1 meter or more in hole O-7), and magnetite-walled veins (Figs. 25-28). In most veins, chalcopyrite occurs not disseminated in the vein quartz, but filling later microfractures, so the sulfide stage
follows the quartz-magnetite stage (S. Moore, written comm., 2004). The main productive granodiorite has magnetite and secondary biotite alteration of the matrix that is cut by (1) ‘A’ veinlets (quartz – magnetite – chalcopyrite ± bornite?) with trace K-feldspar halos, (2) magnetite – quartz veins ± K-feldspar halos. All of the previous vein types are truncated by (3) ‘B’ veinlets (quartz - biotite - magnetite – chalcopyrite ± bornite). The youngest type are (4) veinlets of chalcopyrite - pyrite (Fig. 28). In the early hornblende diorite (Fig. 26) and intra-mineral granodiorite porphyry (Fig. 27), the veinlets are predominantly (1) ‘B’ veinlets (quartz – magnetite ± chalcopyrite) occasionally with K-feldspar halos, (2) magnetite – quartz ± actinolite, (3) quartz – chalcopyrite ± pyrite centerlines with smectite halos. Flakes of molybdenite are locally associated with ‘B’ veinlets in the upper part of the system, whereas in the core of system there is some molybdenite is locally associated with ‘A’ veinlets (quartz – chalcopyrite ± molybdenite) with K- feldspar halos.

Based on core logging and considering all the variety of veinlets, a series of cross sections were produced to illustrate the zoning of hydrothermal features (Figs. 36-65), including vein density (Fig. 49, 64). The highest density of quartz veins is in the core of the main productive granodiorite, where up to >30 vol% veins occurs, with local values to 70 vol%. Quartz veins persist for more than 500 m below the surface (e.g., drill hole MCA-001). The vein density decreases progressively outward.

As shown in cross sections, there is a correlation of abundant magnetite (≥3% as disseminations and veinlets) with the zones of >10% quartz veinlets (Figs. 476, 61).

**Mineralogy of Copper and Gold**
The total sulfide percentage in the project is low; however, macroscopically four sulfides species are recognized: chalcopyrite > pyrite > minor bornite > sparse molybdenite (Figs. 13-17). Chalcopyrite and bornite occur disseminated in the matrix as well as in veinlets. Both constitute the main sulfides for the copper and gold grade. Metallurgical studies suggest that gold grades increase with the abundance of bornite; however, chalcopyrite is the main sulfide controlling the gold grade because of its abundance in the project, though native gold is an important host of gold.

The present distribution of sulfides (Figs. 47 and 62) is described in terms of four sulfide associations and relative abundances of the associated sulfide minerals: (1) mainly pyrite, (2) chalcopyrite ≥ bornite (± pyrite), (3) chalcopyrite > pyrite (± bornite), (4) pyrite > chalcopyrite (± bornite). The area with predominant (1) pyrite is linked to the heterolithic breccia; however, pyrite increases in the surrounding area and higher levels of the system. Association (2) with chalcopyrite > pyrite (± bornite) is associated mainly with main productive granodiorite and partially with intra-mineral granodiorite (near its contacts). Association (4) with pyrite > chalcopyrite (± bornite) encloses the volume of rock containing association (3) with chalcopyrite > pyrite (± bornite). Although there is an absence of bornite in the pyritic area, traces of bornite are distributed in the other assemblages. In sections, there are restricted and isolated areas with significant bornite related to the association of chalcopyrite ≥ bornite (± pyrite), where pyrite is scarce.

The major presence of sulfide (≥1.5%) is localized in the core of system related with main productive granodiorite and decreasing outward (Figs. 48 and 63). There is an isolated area with more than ≥1.5% of sulfide within the fragmental andesite, but it is mostly pyrite.
Grade Distribution and Metal Ratios

The grade contours for Au, Cu, and Mo in cross sections were obtained by contouring the block –model in the cross section, in which the grade estimates were based on a combination of kriging and inverse distance methods. The grade contours for Ag, for which a block model was not available, and all contours of metal ratios were generated directly from drill hole assays. The contours values chosen are approximately the quartiles of all drill hole assays (or metal ratios) reported for the project. Surface contours were generated in ArcGIS using kriging-inverse distance. Mean grades of each element are presented, calculated from all drill hole assays.

Gold

Unconsolidated cover material and scarcity of outcrop prevent adequate rock sampling at the surface; however, some limited gold anomalies occur within and near the center of the system (Figs. 30-31). Surface contours for gold greater than 0.1 ppm have a northwesterly trend. Spatially restricted anomalies to 0.5 ppm Au occur over the early hornblende diorite (Fig. 32).

In cross sections, gold isopleths are oriented vertically, extending downward and remaining open at depth (Figs. 38 and 53). The highest grade zone (≥1.0 ppm) is mainly related to the main productive granodiorite, and gold grades decrease outward from its contact with wall rocks. Within the heterolithic breccia, anomalous gold grades, up to 0.5 ppm, are observed. The mean grade in the deposit is 0.4 g/t Au.

Copper
The distribution of copper and gold at the surface are strongly correlated, such that the contour for Cu > 0.1% nearly corresponds to the contour for +0.5 ppm Au (Figs. 32-33). In cross section, the contour of ≥0.1% Cu (1,000 ppm) widens with depth (Figs. 39 and 54), although there are some restricted areas where modest Cu grades, e.g., ≥0.2 % Cu (2,000 ppm) has the same pattern as gold grades of more than ≥1 ppm. The highest Cu grades also are zoned with respect to the main productive granodiorite (Fig. 30). The mean grade obtained for Cu is 0.13%.

**Molybdenum**

Mo distribution at surface is more extensive than Cu or Au and apparently surrounds the system (Fig. 35). In cross section (Figs. 41 and 56), the core of the system shows Mo grades of <5 ppm; however, the upper part of the system shows grades of >10 ppm and locally >50 ppm. Mo distribution does not directly correlate with the Au and Cu grades. High concentrations of Mo (≥ 25 ppm) are present even in wall rocks such as the early hornblende diorite (Section 3, Fig. 41). The mean molybdenum grade in the deposit is 13 ppm.

**Silver**

On surface, Ag distribution (Fig. 34) is relatively restricted and correlates with Au and Cu distribution, whereas in section (Figs. 40 and 55), grades >0.30 ppm have a large vertical interval and increase with depth. The higher anomalous ≥0.55 ppm Ag coincide with higher grades of Au and Cu. This broad distribution of silver not only is extensive within main productive granodiorite unit, but continues beyond it. The high Ag anomalies are coincident with the heterolithic breccia body (Figs. 30 and 34). The mean grade of silver is 0.73 ppm.
Barium, zinc, and lead

Anomalous Ba (≥ 250 ppm) is most prevalent in the heterolithic breccia bodies and is distal to the upper part of the system. Zn anomalies (≥100 ppm) reside outside of the main productive granodiorite and are distributed near the outer fringes of the cross sections. Occasional strongly anomalous Zn (≥0.25%) is localized at depth on the eastern side of section 3, and apparently related to exoskarn and/or endoskarn. Pb is practically absent in the system.

Metal ratios

Metal ratio contours have been constructed for the cross sections, and all grades for the metals are expressed in ppm. The \( \frac{(Au \text{ (ppm)} \times 10000)}{Cu \text{ (ppm)}} \) ratio shows vertical elongation of the higher contour values (Figs. 42 and 57). The core of the system shows ratios greater than 3 and coincides with the main productive granodiorite, and this ratio gradually decreases outward to less than 1. It reflects the high gold content relative to copper in this deposit.

The \( \frac{Au \text{ (ppm)}}{Mo \text{ (ppm)}} \) ratio shows vertically oriented isopleths for the high values (more than 0.082), and it coincides with the core of the system extending to depth (Figs. 43 and 58). This ratio decreases outward to less than 0.005, which mainly reflects the increase in Mo values outward (Figs. 41 and 56).

The \( \frac{Cu \text{ (ppm)}}{10 \times Mo \text{ (ppm)}} \) ratio also shows a vertical zoning (Figs. 45 and 60), where a ratio of >29 coincides with the core of the system, and it is open at depth. This geometry is explained by the predominance of Cu grade in this region (Figs. 39 and 54). The ratio gradually decreases outward to less than 3 because of the increase in Mo values (Figs. 41 and 56).
The Au (ppm) / Ag (ppm) ratio shows a vertical zoning, with ratio greater than 0.99 elongate at depth and coincident with the core of the deposit (Figs. 44 and 59). This ratio decreases gradually outward to less than 0.25. Although Au and Ag grades correlate, the gold values diminish laterally more rapidly than do silver grades (Figs. 38, 40, 53, and 55).

**Interpretations**

*Relationship between rock types, alteration, and metal distribution*

After evaluating two sets of cross sections, the core of deposit is related to the main productive granodiorite with dominant Au grade up to ≥1 ppm that gradually decrease outward. Moderate to irregular high-grade gold zones occur at the contact of the main productive granodiorite or the intra-mineral granodiorite. Wall rocks consisting of the early hornblende diorite and calc-silicated calcareous basement rocks host spatially restricted gold anomalies, and irregular gold grades are detected within the heterolithic breccia body, probably related to incorporation of previously mineralized clasts. On surface, outcrops above the projection of main productive granodiorite show restricted gold anomalies. In cross section, the high grades for Au (≥1 ppm), Cu (≥0.2%), and Ag (>0.55 ppm) are controlled by, and related to the emplacement of, the main productive granodiorite. Significant Mo values (≥10 ppm), with occasional visual presence of molybdenite in quartz veinlets, are distributed in the apex of the porphyry stock and within the adjacent wall rock. Mo grades of <5 ppm characterize the main productive granodiorite and intra-mineral granodiorite.
The Amaro project is a partially unroofed system, in which the mineralizing intrusion does not crop out at the present surface and the mineralized part of the porphyry system lies beneath the modern surface, in the center of small valley formed by the preferential erosion of an argillic cap. The Amaro porphyry represents a - system centered on anomalies in Au-Cu-Ag. An element that is only weakly enriched at Amaro compared with many other porphyry systems, Mo, is more extensive at the surface than either Cu or Au, such that surface Mo anomalies of 10 ppm are a good exploration guide to Au-Cu-Ag mineralization at depth.

Metal ratios and metal zoning

The main productive granodiorite forms the core of the porphyry system; the core is characterized by Au, Cu, and Ag, though metal ratios indicate the predominance of gold over both copper and silver, which are also strongest here, therefore there is a correlation between these metals. The distribution of Mo, Zn, and Ba preferentially occur outward of main productive granodiorite. Specifically, considerable Mo values are distributed in the upper part of the system. The four metal ratios: Au/Cu, Au/Mo, Cu/Mo and Au/Ag demonstrate correlation. High gold ratios occur preferentially within the main productive granodiorite and continue at depth. The gold ratios and overall metal grades decrease outward from the main productive granodiorite. Because of stronger Mo and Ba in the upper part of the system, it is claimed that Amaro porphyry is a partially eroded system where the cupola and flanks still remain intact but the correspondent high-sulfidation-lithocap is completely eroded.

Due to the predominance of gold grades relative to other metals the metal ratio’s spatial distribution seen in the sections is mostly determined by Au content. Therefore, it
is possible to suggest that these metals were transported and deposited under similar physiochemical conditions, or related to one principal hydrothermal event.

*Evolution of the Amaro hydrothermal system*

Above the main porphyry stock, an area measuring approximately 500 m x 400 m contains quartz veinlets although there are few outcrops due to erosion and unconsolidated cover. At surface, these quartz veinlets are ubiquitous within the area of potassic alteration (C. Schnell, written comm., 2005), primarily within the early hornblende diorite and restricted areas within the fragmental andesite and heterolithic breccia body. Irregular zones of sparse quartz veinlets (commonly associated with thin magnetite veinlets) occur within the argillic altered zone (see above). In outcrop, areas with more abundant quartz veins (1 to 15%) are associated with more intense and coarsely crystalline secondary biotite (Fig. ). Even relatively young units, such as the needle hornblende unit, contain occasional thin magnetite veinlets with sparse sulfides. The area of magnetite veins has a slightly wider distribution than the area of quartz veins, making such magnetite veins a good exploration guide to non-outcropping porphyry systems.

In drill holes, most quartz veins are ‘A’ type of Gustafson and Hunt (1975) and Proffett (2003), but there is textural variety, including coarse quartz-magnetite, multiply-banded quartz-magnetite (some reaching thicknesses of 1 meter or more in hole O-7), and magnetite-walled veins. In most veins, chalcopyrite occurs not disseminated in the vein quartz, but filling later microfractures, so the sulfide stage follows the quartz-magnetite stage (S. Moore, written comm., 2004). The main productive granodiorite has magnetite and secondary biotite alteration of the matrix that is cut by (1) ‘A’ veinlets (quartz –
magnetite – chalcopyrite ± bornite?) with trace K-feldspar halos, (2) magnetite – quartz veins ± K-feldspar halos. All of the previous vein types are truncated by (3) ‘B’ veinlets (quartz - biotite - magnetite – chalcopyrite ± bornite). The youngest type are (4) veinlets of chalcopyrite - pyrite (Fig. ). In the early hornblende diorite and intra-mineral granodiorite porphyry, the veinlets are predominantly (1) ‘B’ veinlets (quartz – magnetite ± chalcopyrite) occasionally with K-feldspar halos, (2) magnetite – quartz ± actinolite, (3) quartz – chalcopyrite ± pyrite centerlines with smectite halos (Fig. ). Flakes of molybdenite are locally associated with ‘B’ veinlets in the upper part of the system, whereas in the core of system there is some molybdenite is locally associated with ‘A’ veinlets (quartz – chalcopyrite ± molybdenite) with K- feldspar halos.

Based on core logging and considering all the variety of veinlets, a series of cross sections were produced to illustrate the zoning of vein density. The highest density of veins is in the core of the main productive granodiorite, where up to >30 vol% veins occurs, with local values to 70 vol%. Veins persist for more than 500 m below the surface (e.g., drill hole MCA-001). The vein density decreases progressively outward.

As shown in cross sections, there is a correlation of abundant magnetite (≥3% as disseminations and veinlets) with the zones of >10% quartz veinlets (Fig. ).

The Amaro gold-bearing porphyry deposit is emplaced into deformed Cretaceous basement, and localized in the intersection of NW, E-W and probably N-S structure. It is aligned within three trends: ‘Cajamarca-Huaraz’ belt, ‘Yanacocha –Chicama’ and NS district trend. The hydrothermal evolution of this deposit is associated with the emplacement of Middle Miocene (~15.7 to ~15.5 Ma) granodiorite to quartz diorite in at least two intrusive phases (main productive granodiorite and intra-mineral granodiorite).
and hosted by the Cretaceous basement and early hornblende diorite (~17 Ma (Longo, 2005)). The hydrothermal system generated by main productive granodiorite is responsible for the high temperature and high oxygen fugacity hypogene sulfide mineral assemblage (chalcopyrite ± bornite) and abundant hydrothermal magnetite. It also generated a well-developed strong potassic alteration zone in the core of system with moderate to weak potassic alteration extending outward. Three suites of potassic alteration have been defined: PTF, PTB and PTP (see above). The most dominant alteration in the system is the PTB. This is seen as strong replacement of primary hornblendes by secondary bt and mt associated with quartz veinlets. Generally more ‘A’ than ‘B’ quartz is shown in the core of the system. Here, ‘A’ quartz veinlets have some halos of K-spar. The quartz veinlets distribution shows a progressive change outward, where the abundance of ‘A’ quartz veinlets dominates below, transitioning to dominantly ‘B’ veinlets in the upper parts. The PTP alteration occurs mostly in the surrounding wall-rock. Propylitic to chloritic alteration grading outward to almost fresh rock is exposed in the distal part of the system. Apparently the corresponding lithocap was eroded and only transported relict boulders remain as evidence. All previous stages were followed by diorite dikes and crosscut by heterolithic breccias. It is suggested that after a minimum of 1 to 1.5 km of lithocap was eroded. The deposit was overlain by syn-eruptive andesitic ‘lahar’ (~12.9 Ma) derived from Condorcana volcanic center (?) located to the ESE. The venting of polygenetic breccias crosscut the previous sequences. Weathering produced the saprolitization especially over the center part of the deposit causing a recessive topography.
The alteration and hypogene veinlet mineralization encountered within the breccia or ‘lahar’ is subject to debate. If, the ‘lahar’ (dated at approx. <12.9 Ma) and breccia are indeed young and the main porphyry mineralization is 15.7 Ma, how can the alteration and hypogene mineralization within the breccias or ‘lahar’ be explained? There are at least three theories: first, the alteration and mineralization are related to the reactivation of main productive granodiorite or intra-mineral granodiorite; second, they are related to deep magmatic mineralizing event different from those encountered in Amaro; third, related to Lindero or Atocha or other hydrothermal center outside of Amaro.

Discussion

Space-time relationship of gold-rich and gold-poor porphyry systems in the region

In the Cajamarca region, 14 porphyry systems, more than 19 epithermal systems, and two magmatic episodes activities have been reported (Gustafson et al., 2004). The oldest Paleogene magmatism of intermediate composition spanned ~57 to ~43 Ma (Davies and Williams, 2005) but without significant hydrothermal activity. The second magmatism group reported spanned ~18 to ~13.5 Ma, but these were productive and contain the majority of porphyry systems in the region. An apparent Late Eocene mineralizing event has been reported at the San Cirilo complex, where diorite-generated skarn and porphyry style mineralization has yielded the age of 36.4 Ma (Pinto, 2006). This magmatism is completely different from those established over the region. The majority of Au-rich porphyry deposits (e.g., La Carpa, Chailhuagón, Perol, Cerro Corona) are hosted in carbonate sedimentary wall rocks and within well-developed potassic alteration zones. High temperature and high oxygen fugacity hypogene mineral assemblages are dominated by chalcopyrite-bornite associated with abundant
hydrothermal magnetite. Whereas, in the gold poor system (e.g., Aurora-Patricia, Michiquillay, Galeno) the mineralized stocks are hosted in fractured sandstone-quartzites ± carbonates associated with lower temperature hypogene assemblages of chalcopyrite and pyrite, and also potassic alteration overprinted by low-grade pyritic phyllic alteration (Davies and Williams, 2005).

This broad comparison suggests that the gold-rich porphyry systems are relatively younger than the gold-poor systems, and are emplaced into calcareous basement. The neighboring gold-poor systems such as Aurora-Patricia, Michiquillay and Galeno have reported ages of 21.30, 19.8 - 18.8 and 17.5-16.5 Ma respectively (Davies and Williams, 2005), whereas Perol, Chailhuagón reported mid- Miocene ages from 15.5 to 16.0 Ma and the youngest Cerro Corona with 13.5 to 14.4 Ma. Although La Carpa is also gold-rich system, the reported age of 17.85 Ma in the volcanic wall rock (Davies and Williams, 2005) can suggest an age similar age to those spanned by gold-poor deposits in the area.

Newest age dates obtained from two Amaro stocks reported 15.7 ± 0.5 Ma for main productive granodiorite and 15.5 ± 0.3 for IMG. These new ages are similar to those obtained for Perol or Chailhuagón, but different from Galeno or Michiquillay. Also Amaro mineralized intrusions are hosted in the Cretaceous calcareous basement and early diorite like other porphyry systems within Conga, Cerro Corona or La Carpa.

After evaluating ages, it is important to point out the apparent N-NW and N-S trend of productive magmatism. From 21.30 Ma in Aurora-Patricia, 19 Ma in Michiquillay, 17Ma in Galeno arriving with 15.5 to 16 Ma in the MCD, and even farther north 13.5 to 14.4 Ma in Cerro Corona.
Not many authors refer to Minas Conga as a district, in fact Vidal (2008) proposed as new district the ‘Michiquillay-Galeno-Conga’ trend. However, based on the new age results and particularly of gold-bearing stocks emplaced within calcareous basement, I propose that Minas Conga is a proper District within the larger ‘Cajamarca-Huaraz’ belt.

**Metal ratios and metal zoning in gold-rich porphyry systems**

The arbitrary definition of gold rich-porphyry systems with gold grades ranging from about 0.4 ppm (Sillitoe, 1979) has been subject to recent refinement. For instance, Kesler et al.(2002), Kirkham and Sinclair (1995) defined gold-rich porphyry copper deposits as those with gold (ppm)/ copper (%) ratios greater than 1:1, with amounts to Cu/Au atomic ratio of about 31000. At the Batu Hijau deposit in Indonesia, an illustrative zoning ratio of gold (ppm) to copper (%) was reported from 1 in the upper part of the deposit to 3 at deeper (Arif and Baker, 2004). These variations correlated with changes in the copper sulfide distribution. Although the bornite has gold inclusions, the main source of gold and copper grades are due to the abundance of chalcopyrite in the system. Microprobe analysis from sulfide at Batu Hijau defined two stages of silver: early bornite containing gold with higher copper lower silver (mean Cu/Ag = 1.2); later chalcopyrite containing gold with lower copper but high silver (mean Cu/Ag = 0.2) (Arif and Baker, 2004). Those gold porphyry systems deficient in copper, such as Maricunga belt (e.g., Verde and Pancho deposits) have reported the highest ratios (ppm Au/% Cu = ~33) (Muntean and Einaudi, 2000). Other systems emplaced to porphyry-skarn deposits emplaced into carbonate rocks report high Ag : Au ratios, such as at Bingham District, Utah. It was observed also that Ag : Au increase outward with constant ratios near the
pluton contact, and ratios increase in the calcareous sediment from 2:1 to 50:1 inside the hornfels/skarn alteration zone (Einaudi, 1990; Jones, 1992).

Jones (1992), after having examined metal zoning reported by workers in numerous gold-bearing porphyry systems, defined four categories: 1) a central gold-copper zone, where gold and copper grade in potassic alteration are well documented (e.g., Dizon, Panguna, Ok Tedi) with base metal zoning outward; 2) an intermediate gold zone between the central copper zone and the lead-zinc zone of porphyry system (e.g., San Manuel-Kalamazoo, Copper Canyon, Robinson, Mt. Milligan etc.); 3) a distal gold zone where some epithermal precious-metal system and gold-bearing porphyry systems have genetic relationships (e.g., Bau, Yauricocha District, La Plata, Barneys Canyon, Melco, and Mercur); 4) systems with multiple gold zones where many districts show central, intermediate and distal gold zones (e.g., Bingham Canyon, Lepanto).

Molybdenum is deficient in many gold-rich porphyrries but occurs as haloes in a few major deposits (e.g., Santo Tomas, Lepanto Far Southeast, Ok Tedi, Bajo de la Alumbrera, Dos Pobres, Saindak); however, there are some exceptions such as the molybdenum-rich core at Bingham (Sillitoe, 1993; Jones, 1992). Most of the gold in Au-Cu porphyry deposits is introduced with the copper minerals during potassic-silicate alteration, therefore the gold and copper grades vary sympathetically. Also silver tends to coexist co-spatially with gold (Sillitoe, 1993) but with minor economic significance (0.5-4 ppm).

In Amaro, the four metal ratios present similar patterns and those are dominated by the high grade of gold distribution in the core of porphyry system. As in the core of Batu Hijau porphyry, the Amaro deposit has an Au : Cu ratio greater than 3 and it is still
open at depth. The increasing Mo above and peripheral to the porphyry stock is demonstrated by the low Au : Mo ratio of <0.022. Unlike the Bingham Deposit, the silver grade and therefore Au/Ag do not show any decrease outward of the system. However, in Amaro some large blocks limestone that have been engulfed by the intrusions and converted to mineralized skarn contain locally high quantities of gold, copper, and lead, zinc and silver. Based on a classification by Jones (1993), Amaro shows a centralized gold-copper zone, where Au and Cu in the core of the deposit attain grades of >1 ppm Au and >0.6 % Cu, with progressive decrease outward. Silver anomalies (> 0.55ppm) are co-existent spatially with high Au and Cu grades. Despite the low grades for silver, millions of dollars in silver resource have been calculated in Amaro and Perol. Minor anomalies of Zn, Pb and Mo increase weakly from the center of the deposit toward the periphery.

The metal ratios for the Amaro project are not fully useful regional exploration because four of them show the same patterns; however, the metal zoning is useful. For example, the high Mo anomalies occur above the ore deposit, or the anomalous silver presence together with high values of gold and copper.

Composition of intrusions in gold-rich porphyry systems

For most porphyry stocks no simple relation has been established between petrologic association and gold-bearing porphyry systems, however, most of these systems have been formed in slightly mafic igneous rocks including diorite, quartz diorite, and felsic to alkali-rich igneous granite and syenite (Jones, 1992; Sillitoe , 1993; Seedorff et al., 2005). Even though quartz monzonite or granodiorite-hosted porphyry systems in the western United States or South America are commonly gold poor; there are some
exceptions such as Fortitude (Nevada), Ajo, Bisbee and Dos Pobres (Arizona) (Jones, 1992). Leveille et al. (1988) proposed that a key in distinguishing gold-rich intermediate intrusions from gold poor ones may be in the oxidation of the intrusive rocks and/or the relatively reduced crustal units could buffer the redox state of magmas ascending through them.

Intrusive compositions for some major Cu-Au porphyry deposits include the following: Batu Hijau which is related to intermediate tonalite unit (Arif and Baker, 2004), Cerro Casale at northern Chilean Maricunga Belt hosted by diorite and granodiorite (Palacios et al., 2001). Even though copper-gold deposits appear to accompany alkalic stocks; nevertheless the most gold-rich deposits such as Grasberg, Lepanto Far Southeast, Lobo and Marte occur with low potassium calc-alkalic diorite and quartz diorite rather than alkaline porphyries (Sillitoe, 1993). Gold rich porphyry deposits such as Grasberg, Bingham Canyon, and Kal’-maky are the exceptions where the mineralizing intrusions have high K calc-alkalic compositions (Cooke, 2005, Sillitoe, 1993). Another observation was that the three super-giant gold deposits and four of the giant deposits are associated with high K calc-alkalic intrusions, contrasting to the giant copper porphyry deposits (Cook, 2005). Seedorff et al. (2005) suggest that the formation of gold rich systems may be a continuum with the porphyry Cu class in particular with the tonalitic-granodioritic porphyry Cu-(Au-Mo) subclass. The Cerro Casale deposit in the Maricunga belt of Chile and Cerro Corona in Peru are closest to being transitional into porphyry Cu class mentioned previously. Another example is the Cadia district in Australia, where there is the largest known accumulation of gold associated with an alkaline porphyry systems (Cooke, 2005). At Bajo de La Alumbrera in Argentina, the
mineralization is hosted in dacite porphyry stock emplaced in comagmatic andesitic (Sillitoe, 1979).

The SiO₂ content from whole rock geochemistry analyses for numerous productive intrusions show interesting correlation. For example, results for numerous productive intrusions of the Maricunga belt in Chile reported SiO₂ values lower than 61% (Muntean and Einaudi, 2000). For the main productive intrusion defined as intermediate tonalite in Batu Hijau, whole rock geochemical assays in the fresh and potassic zone report 66.32% and 66.71 % SiO₂ respectively (Idrus et al., 2009). In the case of Bajo de La Alumbrera the range of SiO₂ for the different porphyries varies from 57 to 67%. Raw whole rock geochemical data using X-ray fluorescence (XRF) analyses reported 62.50% for one of mineralized intrusions from Chailhuagón (hornblende-biotite diorite?), or 59.70% SiO₂ for Huaylamachay Sur mineralized intrusions (hornblende-biotite diorite?), or in the case of hornblende-biotite diorite? from La Carpa with 62.62% SiO₂ (Davies and Williams, 2005).

In Amaro the field macroscopic definition for the productive and intramineral unit were granodiorite to dacite porphyry. The whole rock geochemistry analyses for main productive granodiorite and intra-mineral granodiorite reported SiO₂ values lower than 62%. These numbers are closely similar to those reported in Maricunga belt or similar to those reported in the Cajamarca region for gold-rich porphyry systems. Therefore, if intermediate mafic intrusions are related to gold bearing porphyry systems at northern Peru, one of the immediate exploration tools may be systematic whole geochemistry through the District to identify intrusions with mineral assemblages comparable to those of productive porphyries.
Veins, mineralization and alteration associated with gold-rich porphyry systems

At least six broad alteration types have been reported in silicate rocks in and surrounding gold-rich porphyry deposits. The spatial distribution of veins, veinlets and sulfide mineralization are determined by the specific alteration assemblages (Sillitoe, 1993, 2000). Following are descriptions of the alteration types from deep to outward. Sillitoe (1993, 2000) described the alteration assemblages within or adjacent to the core of the system as having a Ca-Na silicate assemblage (actinolite, actinolitic hornblende, albite or oligoclase) that is generally deficient in sulfides. Some gold rich porphyry deposits are characterized by hybrid Ca-Na and K-silicate assemblages (e.g., Cabang Kirica).

K-silicate (potassic) is present in nearly all gold-rich porphyry deposits and characterized by the presence of replacement and veinlet-filling secondary biotite, called “EB type” (Gustafson and Quiroga, 1995). The biotite may be accompanied by hydrothermal K-feldspar and/or actinolite. The major variety of multi-episodic quartz veinlets (stockwork, and/or subparallel) comprises 10 to 90 volume percent of K-silicate alteration (e.g., Batu Hijau). The planar to slightly sinuous veinlets may be composed of vitreous, granular quartz. These can be millimeters to several centimeters in width, discontinuous in form, and commonly lack prominent alteration halos, although K-feldspar and/or biotite may be observable. Distinctive gray banded quartz veinlets within K-feldspar occur in several Au porphyry deposits. The darker bands within the veinlets may result from repeated opening and quartz introduction or due to concentration of magnetite – pyrite. Such occurrences are documented in the Maricunga Belt (Vila et al., 1991; Muntean and Einaudi, 2000, 2001) and in Northern Peru below Yanacocha Norte.
oxide gold ore (Gustafson et al., 2004) as well as in the Chailhuagón and Perol porphyries at MCD. More than 80% of gold-rich porphyries have greater amounts of hydrothermal magnetite than other copper deposits (Sillitoe, 1993), averaging 3 to 10 vol. percent in many K-silicate zones especially.

Chalcopyrite and pyrite are the dominant hypogene sulfides in the zone of the K-silicate alteration. Chalcopyrite occurs as finely disseminated grains in quartz veinlets, in association with magnetite, or alone in veinlets and disseminated forms. Total pyrite contents are typically fairly low, with pyrite/chalcopyrite ratios ranging from <0.5 to 3. The core zones of some deposits are essentially devoid of pyrite. However, higher content of pyrite has been observed as a product of superimposed intermediate argillic alteration. Bornite is preferentially distributed at depth and in the central parts of K-silicate alteration zones, where chalcopyrite/bornite ratios can be <3. Bornite could be accompanied by hypogene digenite and chalcocite (e.g., Batu Hijau, Chailhuagón (pers. Comm., L. Ruiz, 2009). Basically, gold-rich porphyry deposits are deficient in molybdenum or Mo is a minor economic component distributed at peripheral areas (e.g., Bajo de La Alumbrera (Ulrich and Heinrich, 2001)). However, there are some exceptions with prominent Mo contents, such as Bingham, Ok Tedi, and Skouries (Sillitoe, 2000).

Although, Alumbrera and Cadia deposits both contain dominantly chalcopyrite-rich ores (Ulrich and Heinrich, 2001); sulfide distribution in Batu Hijau varies from bornite > chalcopyrite mineralogy in the upper part to chalcopyrite > bornite in the deeper part, with predominance of chalcopyrite-pyrite (Arif and Baker, 2004). This distribution is unusual. For example, Arif and Baker (2004) documented at Batu Hijau two pyritic halos —one at the upper part, and the other at deeper part— that border the
predominant chalcopyrite-pyrite assemblages. Also in this deposit bornite shows unusual distribution, with major presence outward.

Gold occurs in native metal form and in high-fineness but sometimes subsidiary amounts of auriferous tellurides occur as possible late stage additions as is documented at Bingham, Dos Pobres etc. (Sillitoe, 1993). Silver grade due to platinoids (especially palladium) are reported in close association with gold and copper in some deposits (e.g., Santo Tomas II, Skouries) (Sillitoe, 1993). At Batu Hijau, high gold and low silver are related to early bornite stage. Microprobe analysis indicated that most of the native gold contains significant silver and copper (Arif and Baker, 2004).

Propylitic alteration is reported as outer halos and commonly confined to the wall rocks of gold-rich porphyry system. The typical assemblage contains chlorite, epidote, calcite, occasionally with or without albite, actinolite, and magnetite. Upward transition to chloritic with absence of epidote is observed in the shallow peripheries of gold-rich porphyry systems, which indicate declining temperature. Veinlet and disseminated pyrite, ranging from 3 to locally >20 vol. percent, dominates the sulfide content within this propylitic alteration. Scarce amounts of chalcopyrite, tetrahedrite, sphalerite, and galena are common in propylitic zones, locally concentrated in faults or fractures as quartz-carbonate veins (Sillitoe, 1993, 2000).

Intermediate argillic alteration is widespread and varies in both intensity and mineralogy. Typically it occurs as pale-green overprinting to K-silicate assemblages, especially in the upper parts of porphyry (e.g., Marte, (Vila et al., 1991), and Cerro Corona (James and Thompson, 1997)). The assemblages may include sericite, illite, chlorite, calcite and smectite. Magnetite is variably altered to martite. Pyrite and
specular hematite, with or without chalcopyrite are introduced as veinlets. Pre-existing stockwork quartz veinlets survive the overprinting alteration. Locally the gold and/or copper grades increase over the pre-existing K-silicate alteration.

Sericitic (phylllic) alteration in porphyry deposits is characterized by white to gray quartz-sericite-pyrite assemblages displaying partial to almost complete destruction of previous alteration texture. This alteration is common around K-silicate cores at many porphyry copper-molybdenum deposits, but not widely developed in gold rich-porphyry deposits. Some deposits such as at Bajo de La Alumbrera (Sillitoe, 2000; Proffett, 2003; Ulrich and Heinrich, 2001) or Perol display sericitic alteration. Only localized sericitic alteration has been reported at Panguna, Wafi, etc. (Sillitoe, 2000), or the Chailhuagón deposit. The sole sulfide mineral in quantities ranging from 5 to >20 vol. percent is pyrite.

Advance argillic alteration is ubiquitous in the upper, commonly volcanic-hosted part of gold-rich porphyry systems, where it constitutes laterally extensive lithocaps as thick as 1 km (Sillitoe, 1993, 2000). This alteration could be coeval with early K-silicate alteration, but in many deposits where lithocaps are preserved, it clearly overprints K-silicate, propylitic and intermediate argillic alteration. Also the sericitic alteration appears to be transitional upward to advanced argillic alteration (Sillitoe, 1999). This process destroys all pre-existing silicates and sulfides, and preserves only barren quartz veinlets. Pyrite-marcasite comprises 10 to 20 vol. percent of advanced argillic zones. Also enargite and luzonite replace the iron sulfides in restricted parts of some advance argillic alteration (Sillitoe, 2000). Restricted skarn alteration could occur where
carbonate rocks are present or involve the pluton within the gold rich-porphyry systems (e.g., Ok Tedi, Kingking, Majdanpek, Bingham, Cerro Corona, Perol).

At the Perol Au-Cu porphyry, the higher metal grades are associated with the phyllic alteration assemblage whereas the neighboring Chailhuagón porphyry the higher Au-Cu grades occur within the zone of potassic alteration. Therefore, numerous authors claim that potassic magnetite>secondary biotite ± K-feldspar alteration is the main control for the gold-rich porphyry systems.

There is no supergene copper enrichment because of the low pyrite content and relatively high neutralizing capacities of most copper-gold-bearing K-silicate zones. However, there are some abnormal examples with gold enrichment, such as those reported in Bingham, and Ok Tedi (Sillitoe, 1993, 2000).

At the Amaro project the mineralization zones and veinlet distribution are also linked with specific alteration assemblages. Most of the typical alteration assemblages have been documented in the Amaro deposit except for phyllic and advanced argillic. However, silica alunite ribs and detrital acid-sulfate altered boulders suggest that these are remnants of an eroded lithocap. At surface Amaro displays a central zone of potassic alteration surrounded by argillic alteration that transitions outward to propylitic- chloritic alteration.

The spatial density of ‘A’ and ‘B’ quartz veinlets is greater within the zone of potassic alteration whereas the magnetite veinlets have widespread expression outward of the potassic zone. At surface, argillic alteration is most prevalent, but the geologic cross sections (interpreted from drill core logging) indicate that potassic alteration is most predominant at depth within the deposit. Three facies of potassic alteration were
classified. The predominant facies has secondary biotite, hydrothermal magnetite and traces of K-feldspar associated with a high density of ‘A-B’ veinlets. Copper, gold, and minor silver grades correlate directly with intensity of quartz veining within this facies. Dimensions indicated for the core of the main phase porphyry are: 200m x 250m x 500m. This core exhibits the strongest potassic alteration containing up to 70% by volume ‘A-B’ veinlets. The veining and metal grades decrease laterally but this zone remains open at depth. This zoning is unusual because most of porphyry systems display denser veinlets in the cupola with predominantly ‘B’ quartz veinlets. Distribution of Mo is irregular and mostly distal with no economic importance as at Bajo de la Alumbrera.

The sulfide mineral assemblage in the core of the system is typically chalcopyrite>pyrite (trace bornite), with a transition outward to pyrite>chalcopyrite (trace bornite). The pyrite- dominant zone is related to the waning stage of mineralization and/or distal zoning. Some restricted areas show the predominant bornite>chalcopyrite (trace pyrite).

The broad and distal halo of magnetite veinlets at surface may provide a useful guide for the future discovery of additional concealed gold-rich systems within the Minas Conga District.

**Conclusions**

The Amaro deposit shows correlation of high grade of gold (> 1.0 ppm) with Cu (0.2%) and Ag (0.55 ppm), whereas Mo deposition is peripheral, and trace to weak Pb-Zn increase outward of the main productive granodiorite. The metal ratios are dominated by the high Au grades whereby Au:Cu, Au:Mo, Cu:Mo, and Au:Ag present high ratios
within the main productive granodiorite. The hydrothermal mineralization is related to the main productive granodioritic intrusion (15.7 Ma) and intramineral intrusion. There exist a direct relation between quartz veinlet volume (>10%), hydrothermal magnetite (>3%), potassic alteration and sulfide content. The similar pattern is observed at surface. The total sulfide percentage, basically hypogene sulfides, is low with persistent sulfides (up to 5%) in the main productive granodiorite, with a clearly predominant chalcopyrite>pyrite (± bornite) assemblage. The total SiO₂ content for Main Granodiorite Porphyry and intramineral phases is approximately 62%.

In conventional classification scheme (Sillitoe, 1979, 2000; Kesler et al., 2002; Seedorff et al., 2005; Jones, 1992) Amaro is a gold-centered, gold-rich porphyry system. It is emplaced in one the most gold-rich clusters of deposits in the world and localized over the flat-slab subduction arc setting. Like the other prominent gold rich porphyry systems in the Cajamarca region, Amaro was intruded into carbonate basement rocks. The mineralizing porphyries within Amaro have total SiO₂ contents similar to other gold-rich porphyry systems with predominant oxide magmatic productive intrusions reported elsewhere in the world.

Although deposits in the Minas Conga district follow the northwestern Miocene mineralized trend, the hydrothermal evolution and latest geochronology studies confirm that the cluster of porphyry deposits in the Minas Conga district are mid-Miocene and range from 15.5 to 16.0 Ma. These ages are differ from Galeno or Cerro Corona porphyry deposits that lie adjacent to the Minas Conga district. Therefore, it is firmly suggested that Minas Conga is its own proper district with distinctive characteristics.
There are still many questions un-answered such as: the depth of emplacement of Amaro and other porphyry clusters in the district; if the wall rock really had a key role for the gold rich porphyry deposits; and detailed understanding of the volcanic geology in order to infer the presence of porphyry deposits in the subsurface.
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Table 1: WR-1 package analysis for major elements by lithium metaborate/tetraborate fusion (Inductively Coupled Plasma) ICP/ (Optical Emissions Spectroscopy) OES -method.

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<tr>
<th>Field description</th>
<th>ITEM NO.</th>
<th>SAMPLE CODE</th>
<th>SiO2</th>
<th>Al2O3</th>
<th>Fe2O3</th>
<th>CaO</th>
<th>MgO</th>
<th>Na2O</th>
<th>K2O</th>
<th>TiO2</th>
<th>P2O5</th>
<th>MnO</th>
<th>BaO</th>
<th>Cr2O3</th>
<th>LOI</th>
<th>Total</th>
<th>C</th>
<th>S</th>
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<tr>
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<td>MCA-021</td>
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<td>15.81</td>
<td>4.56</td>
<td>4.61</td>
<td>1.86</td>
<td>3.06</td>
<td>2.65</td>
<td>0.28</td>
<td>0.25</td>
<td>0.06</td>
<td>0.08</td>
<td>0.04</td>
<td>4.08</td>
<td>98.02</td>
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<td>0.03</td>
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<td>9.2</td>
<td>3.94</td>
<td>1.26</td>
<td>2.2</td>
<td>5.09</td>
<td>0.22</td>
<td>0.25</td>
<td>0.08</td>
<td>0.05</td>
<td>0.03</td>
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<td>98.08</td>
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<td>0.17</td>
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<tr>
<td>Andesitic volcaniclastic, lahar</td>
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<td>MCA-OUTCROP</td>
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<td>15.72</td>
<td>6.04</td>
<td>5.12</td>
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Table 2: WR-2 package for trace elements by the ICP/OES method.

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<th>Cu (ppm)</th>
<th>Nb (ppm)</th>
<th>Ni (ppm)</th>
<th>Rb (ppm)</th>
<th>Sc (ppm)</th>
<th>Sr (ppm)</th>
<th>V (ppm)</th>
<th>Y (ppm)</th>
<th>Zn (ppm)</th>
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<td>6</td>
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<td>98</td>
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<tr>
<td>Main productive granodiorite</td>
<td>2</td>
<td>MCA-013</td>
<td>&lt;5</td>
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FIGURE CAPTIONS

Fig. 1: Regional geology map and the location of the Minas Conga district and other mineral districts in northern Peru that lies within a structural corridor defined by the ‘Yanacocha-Chicama’, northwestern Andean Trend and north-south local district trend. This map, compiled by Veliz and Teal (2001), was modified based on the information by Longo (2005).

Fig. 2: Continental tectonic elements of the Andean margin of South America, and the location of young (<20 Ma) gold-rich, gold poor porphyry and high sulfidation deposits. Triangles are active volcanoes. The location of the Minas Conga district is indicated (modified from Davies, 2002; Rosembaun et al. 2005; Cooke, 2005; Ramos, 2009).

Fig. 3: Tectonic framework of the northern Peruvian Andes (modified from Davies, 2002).

Fig. 4: Satellite image of the Amaro deposit.

Fig. 5: Photograph showing a billet picture corresponding to marbleized Yumagual limestone with sporadic diopside. Sample came from MCA-002, 523.60m.

Fig. 6: Photomicrograph corresponding to MCA-002, 523.60m, Yumagual limestone. Traces of pyrrhotite, magnetite, chalcopyrite, and sphalerite have been observed.

Fig. 7: Photograph corresponding to the early hornblende diorite in outcrop. This unit presents medium homogeneous texture with potassic alteration.
Stockwork veinlets are shown. The inserted small picture shows the
detailed texture mentioned.

Fig. 8: Photograph of early hornblende diorite from drill hole MCA-07 (275.10m)
showing uniform texture with some phenocrysts of plagioclase. Mafic
mineral sites are completely altered. Note the presence of magnetite
veinlets on the right side.

Fig. 9: Photomicrograph from MCA-07 (275.10m); plagioclase (PGLs)
phenocrysts partially altered for carbonates (CBs) surrounded by matrix
altered to micro-crystalline quartz (qz). Black shapes represent abundant
opaque minerals (OPs) (crossed nicols, transmitted light, width of picture
1.68mm).

Fig. 10: Photograph from the Amaro Mirador diorite, with hornblende and
plagioclase phenocrystals, weakly chloritized.

Fig. 11: Photograph corresponding to MCA-13 (367.40m). This interval is
considered to be the main productive granodiorite unit with 1.5 ppm Au
and 0.39 % Cu. There are multistage quartz veinlets. Mafic sites are
replaced by magnetite-chlorite and weak sericite-chlorite alteration can be
observed around some quartz veinlets. Sulfide are filling or cross-cutting
the quartz veinlets. All of these process overprinting the potassic
alteration.

Fig. 12: Photomicrograph corresponding to MCA-013 (367.4m) with plagioclase
in the matrix pervasively altered to clays, carbonates, chlorites and
opales. This alteration also occurs as disseminations and filling of microfractures in association with multistage quartz veinlets (transmitted light, parallel nicols; width of picture 3.36 mm).

Fig. 13: Photomicrograph for another location at MCA-013 (367.4 m). Quartz veinlets are filled by pyrite. Pyrite microfractures are filled by later chalcopyrite (reflected light; width of picture 170µ).

Fig. 14: Photomicrograph for another spot at MCA-013 (367.4 m). Magnetite grains are emplaced along a microfracture in the gangue. Inside the magnetite are observed bornite and chalcopyrite inclusions (reflected light; width of picture 420µ).

Fig. 15: Photomicrograph corresponding to MCA-13 (506m) defined as main productive granodiorite. Note microfracture in gangue filled by magnetite. This magnetite has numerous chalcopyrite and bornite inclusions. In the center of the picture, bornite contains a chalcopyrite inclusion. At this location, opaque minerals are in the matrix but not in veinlets (reflected light; not polarized; width of picture 400µ).

Fig. 16: Photomicrograph corresponding to another portion of MCA-13 (506m). Chalcopyrite and hematite are seen in quartz veinlets. Hornblende is replaced by secondary biotite with later partial alteration by chlorite and clay. In other views there is magnetite associated with chalcopyrite replacing the mafic minerals. Some transverse microfractures within the quartz veinlets are filled by chalcopyrite. Chalcopyrite is present not only
in veinlets, but also in the matrix and within magnetite (reflected light with polarizer; width of picture 4000µ).

**Fig. 17:** Photomicrograph corresponding to MCA-027 (130.25m) and defined as early hornblende diorite. This interval reported 2.2 ppm Au and 0.26 % Cu in endoskarn. It shows one grain of gold (approximately 20x8 microns) found locked within chalcopyrite in a band of calcite along the contact (reflected light).

**Fig. 18:** Photograph corresponding to Q-2 (406.60m) defined as intra-mineral granodiorite. It shows that thin unit crosscuts stockwork-veined main productive granodiorite.

**Fig. 19:** Photomicrograph corresponding to MCA-013 (418.4m) defined as intra-mineral granodiorite. Notice amphiboles partially replaced by carbonate and some opaque minerals. In other locations it is possible to see biotite partially altered and replaced by an opaque mineral (transmitted light; width of picture 480µ).

**Fig. 20:** Photograph showing the pseudo-stratified coarse fragmental unit, cropping out in the south. Picture is looking west. In the inserted small picture there is shown a subrounded ~1 m diameter boulder.

**Fig. 21:** Photograph showing ‘lahar’ textures similar to those in figure 20. The large picture shows the monolithic subrounded character for the sample coming from an outcrop identified as 10_LHR. The inserted small picture corresponds to drill core sample from MCA-01 (11.60m).
Fig. 22: Photomicrograph to the outcropping (10_LHR). The picture shows a pyrite grain replacing hornblende and other mafic minerals. At the right side there are broken crystal fragments. In the matrix are also broken and subhedral crystals (reflected light, width of picture 4000µ). The lower picture shows numerous euhedral to subhedral crystals and some broken crystals. These observations were for the matrix and fragments. Opaque minerals are present in then center matrix of broken crystals. Numerous corroded plagioclase crystals are partially replaced by weak clay carbonate. Some plagioclase is nearly fresh. Hornblende (brown) grains are altered and corroded. In other locations, calcite veinlets cut fragments and cut fragments and matrix (transmitted light; width of picture 4000µ).

Fig. 23: Photograph showing the outcropping needle hornblende porphyry with tiny magnetite veinlets. In the inserted small picture there is a hand sample of needle hornblende porphyry texture. Observe the homogeneous texture and certain aligned hornblendes.

Fig. 24: Photograph showing a heterolithic breccia in drill core of MCA-004 (252m). Stockwork fragment shows clay-sericite alteration that overprinted the earlier potassic alteration in the matrix.

Fig. 25: This photograph correspondent to early hornblende diorite in drill core (MCA-021, 65m), showing development of the following sequence of veinlets: 1) Quartz-magnetite±tremolite vein with K-spar halo, 2) Magnetite-Quartz, 3) Quartz ± centerlines of chalcopyrite and pyrite with smectite halos.
Fig. 26: The photograph corresponds to early hornblende diorite in drill core (MCA-018, 200.70m). In the matrix there is secondary magnetite and biotite. Also sequential veinlets are developed: 1) Magnetite veinlet, 2) ‘B’ Quartz ± magnetite ± chalcopyrite, 3) Magnetite ± quartz, 4) ‘B’ Quartz-chalcopyrite ± bornite.

Fig. 27: The photograph corresponds to intra-mineral granodiorite in drill core (Q-2, 562.50m). The following assemblages were superimposed over the early stage magnetite-secondary biotite in the matrix: 1) Quartz-magnetite ± chalcopyrite, 2) Actinolite - magnetite ± quartz with Kf halos, 3) Quartz-magnetite-chalcopyrite.

Fig. 28: The photograph corresponds to main productive granodiorite (MCA-001, 696.50m). This picture shows the core of the system with pervasive quartz veinlets developed (> 50 % total volume). The veinlets developed in the following sequence: 1) ‘A’ veinlets, 2) ‘B’ veinlets, 3) ‘B’ Quartz rimmed by magnetite, 4) Chalcopyrite ± pyrite veinlets.

Fig. 29: Panoramic picture of the Amaro deposit, looking north, showing extent of main types of alteration.

Fig. 30: Interpretive geologic map of the Amaro project, showing drill hole locations, cone for $ 500 /Oz Au, veinlets and magnetite distribution in outcrop.
Fig. 31: Interpreted alteration map of the Amaro project, showing drill hole locations, cone for $ 500 /Oz Au, veinlets in outcrop, and magnetite in outcrop.

Fig. 32: Surface gold contour map

Fig. 33: Surface copper contour map

Fig. 34: Surface silver contour map

Fig. 35: Surface molybdenum contour map

Fig. 36: Section 3, interpretive geologic map showing cone for $ 500 /Oz Au, drill hole locations.

Fig. 37: Section 3, interpretive alteration map showing cone for $ 500 /Oz Au, drill hole locations and main productive granodiorite shape.

Fig. 38: Section 3, gold grade contour showing cone for $ 500 /Oz Au, drill hole locations, and main productive granodiorite shape.

Fig. 39: Section 3, copper grade contour, showing cone for $ 500 /Oz Au, drill hole locations and main productive granodiorite shape.

Fig. 40: Section 3, silver grade contour, showing cone for $ 500 /Oz Au, drill hole locations and main productive granodiorite shape.

Fig. 41: Section 3, molybdenum grade contour, showing cone for $ 500 /Oz Au, drill hole locations and main productive granodiorite shape.

Fig. 42: Section 3, Au x 10000 : Cu metal ratio, showing cone for $ 500 /Oz Au, drill hole locations and main productive granodiorite shape.
Fig. 43: Section 3, Au : Mo metal ratio, showing cone for $500/Oz Au, drill hole location and main productive granodiorite shape.

Fig. 44: Section 3, Au : Ag metal ratio, showing cone for $500/Oz Au, drill hole location, and main productive granodiorite shape.

Fig. 45: Section 3, Cu : 10 x Mo metal ratio, showing cone for $500/Oz Au, drill hole locations and main productive granodiorite shape.

Fig. 46: Section 3, showing total magnetite distribution, cone for $500/Oz Au, drill hole locations and main productive granodiorite shape.

Fig. 47: Section 3, showing sulfide mineral assemblage distribution, cone for $500/Oz Au, drill hole locations and main productive granodiorite shape.

Fig. 48: Section 3, showing total sulfide distribution, cone for $500/Oz Au, drill hole locations and main productive granodiorite shape.

Fig. 49: Section 3, showing the distribution of quartz veinlets, cone for $500/Oz Au, drill hole locations and main productive granodiorite shape.

Fig. 50: Section 3, showing the geochemical zoning distribution, cone for $500/Oz Au, drill hole locations and main productive granodiorite shape.

Fig. 51: Section 9, interpretive geological cross section showing cone for $500/Oz Au, drill hole locations.

Fig. 52: Section 9, interpretive alteration cross section showing cone for $500/Oz Au, drill hole locations and main productive granodiorite shape.

Fig. 53: Section 9, gold grade contour showing cone for $500/Oz Au, drill hole location and main productive granodiorite shape.
Fig. 54: Section 9, copper grade contour, showing cone for $ 500 /Oz Au, drill hole locations and main productive granodiorite shape.

Fig. 55: Section 9, silver grade contour, showing cone for $ 500 /Oz Au, drill hole locations and main productive granodiorite shape.

Fig. 56: Section 9, molybdenum grade contour, showing cone for $ 500 /Oz Au, drill hole locations and main productive granodiorite shape.

Fig. 57: Section 9, Au x 10000 : Cu metal ratio, showing cone for $ 500 /Oz Au, drill hole locations and main productive granodiorite shape.

Fig. 58: Section 9, Au : Mo metal ratio, showing cone for $ 500 /Oz Au, drill hole location and main productive granodiorite shape.

Fig. 59: Section 9, Au : Ag metal ratio, showing cone for $ 500 /Oz Au, drill hole location and main productive granodiorite shape.

Fig. 60: Section 9, Cu : 10 x Mo metal ratio, showing cone for $ 500 /Oz Au, drill hole locations and main productive granodiorite shape.

Fig. 61: Section 9, showing total magnetite distribution, cone for $ 500 /Oz Au, drill hole locations and main productive granodiorite shape.

Fig. 62: Section 9, showing sulfide mineral assemblage distribution, cone for $ 500 /Oz Au, drill hole locations and main productive granodiorite shape.

Fig. 63: Section 9, showing total sulfide distribution, cone for $ 500 /Oz Au, drill hole locations and main productive granodiorite shape.

Fig. 64: Section 9, showing distribution of total quartz veinlets, cone for $ 500 /Oz Au, drill hole locations and main productive granodiorite shape.
Fig. 65: Section 9, showing the geochemical zoning distribution, cone for $500/\text{Oz Au}$, drill hole locations and main productive granodiorite shape.
Appendices
### Table I. U-Pb geochronologic analyses.

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**Appendix 1:** Zircon analysis from MCA-009 (intra-mineral granodiorite), showing concentration and ratios.
Appendix 2: Concordia graphic for zircon analysis from MCA-009 (intra-mineral granodiorite), showing only the total considered values population.
Appendix 3: Plot of 206Pb/238U ages of individual spot analyses on the IPG  (MCA 009)

Final Age = 15.5 ± 0.3 [1.8%]
Systematic Error Included
MSWD = 0.85
### Table 2. U-Pb geochronologic analyses.

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Appendix 4: Zircon analyses from MCA-013 (main productive granodiorite), showing concentration and ratios.
Appendix 5: Concordia graph for zircon analyses from MCA-013 (main productive granodiorite), showing only for the total considered values population.
Appendix 6: Plot of 206Pb/238U ages of individual spot analyses on the main productive granodiorite (MCA 013)
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<th>± 206Pb*</th>
<th>± error</th>
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<td>235U* (%)</td>
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Appendix 7: Zircon analyses from 10 LHR (lahar), showing concentration and ratios
Appendix 8: Probability density for the total ages obtained for 10_LHR (lahar).
Appendix 9: Concordia graphic for zircon analyses from 10_LHR (lahar), showed just for the restricted valuable population.
Appendix 10: Plot of $^{206}$Pb/$^{238}$U ages of individual spot analyses on the 10_LHR (lahar)
Fig. 1
CAJAMARCA LEGEND

QUATERNARY
- Alluvial_Colluvial (AL) / Glacial_moraine (Gl)

INTRUSIVE ROCKS
- Andesite
- Dacite Porphyry
- Diorite Eocene Intrusions

TERTIARY VOLCANICS
- Frailones Volcanic

UPPER CRETACEOUS
- Superior
- Inferior
- Yanacocha Volcanic Complex
- Undivided Pyroclastic rocks

INTERMEDIATE CRETACEOUS
- Chota F: conglomerates, tuffs, sandstones
- Cenedit F: thin shale interbedded with limestone

LOWER CRETACEOUS
- Farrat F: sandstone
- Santa-Carhuaz F: thin dark gray limestone and thin-bedded shale
- Chinu F: thick-bedded massive quartzite

STRUCTURES
- Anticline Axes
- Syncline Axes
- Volcanic Vents
- Porphyry Deposits
- Hydrothermal Alteration
- Base Metals Veins and lodes: Zn-Pb-Ag-Cu
- Marbleized & Weak Skarn

SIMBOLS
- F: Formation
- G: Group

Fig. 2
Fig. 3
Fig. 5
Fig. 10
Fig. 12
Fig. 22
Fig. 26
Fig. 29

Argillic Alteration

Endoskarn

Area of Potassic Alteration, Magnetite and “A” and “B” Qtz veining
Fig. 30
Fig. 32
Fig. 33
Fig. 34
LEGEND

- Explosive Breccia
- Andesitic Lahar
- Intramineral Granodiorite
- Main Productive Granodiorite
- Amaro Mirador Diorite
- Early Hornblende Diorite
- Limestone

Fig. 36
LEGEND
Marble
ENSg / SKg
ENSpx / SKpx
Argillic
Propylitic
Intermediate Argillic
 Partial Potassic (PTP)
Biotite Potassic (PTB)
Feldspar Potassic (PTF)

Fig. 37
Gold grade (ppm)
- 0.00 - 0.10
- 0.10 - 0.30
- 0.30 - 0.50
- 0.50 - 0.75
- 0.75 - 1.00
- 1.00 - 1.50
- >1.50

Fig. 38
Fig. 39
Molybdenite grade (ppm)

- 0.00 - 5.00
- 5.00 - 10.0
- 10.0 - 25.0
- 25.0 - 50.0
- 50.0 - 100.0
- 100.0 - 250.0
- > 250.0

MCA-001, MCA-004, MCA-005, MCA-006, MCA-011, MCA-013, MCA-017, MCA-021, MCA-029

9,240,500 N, 9,241,000 N, 9,241,500 N

3,400 V, 3,600 V, 3,800 V

250 meter

MPG shape

Cone $500 /Oz Au

Fig. 41
Fig. 42
Fig. 43
Au:Ag RATIO
0.005 - 0.150
0.150 - 0.300
0.300 - 0.550
0.550 - 2030

MCA-001
MCA-004
MCA-005
MCA-006
MCA-011
MCA-013
MCA-017
MCA-021
MCA-029

O-7
Q-2
Q-5

9,240,500 N
9,241,000 N
9,241,500 N
3,400 V
3,600 V
3,800 V

250 meter

Cone $500 /Oz Au
MPG shape

Fig. 44
Cu:10*Mo RATIO

- 0.040 - 3.92
- 3.92 - 11.5
- 11.5 - 29.4
- 29.4 - 5100

MCA-001, MCA-004, MCA-005, MCA-006, MCA-011, MCA-013, MCA-017, MCA-021, MCA-029

Fig. 45
Sulfide Assemblages zoning

- **Py Zone**
- **Cp ≥ Bn (±Py)**
- **Cp > Py (±Bn)**
- **Py > Cp (±Bn)**

**Fig. 47**
Total Sulfide Distribution (%)

- 0.1 - 0.5
- 0.5 - 1.0
- 1.0 - 1.5
- 1.5 - 5.0
- 5.0 - 20.0

Fig. 48
MCA-001
MCA-004
MCA-005
MCA-006
MCA-011
MCA-013
MCA-017
MCA-021
MCA-029

Fig. 49
GEOCHEMISTRY ZONING

Ba >= 500 ppm
Pb >= 50 ppm
Mo >= 10 ppm
Zn >= 100 ppm
Ag >= 0.5 ppm
Mo >= 10 ppm
Cu >= 1000 ppm
Au >= 0.3 ppm
Zn >= 100 ppm
Ba >= 500 ppm
Pb >= 50 ppm
Mo >= 10 ppm
Zn >= 100 ppm
Ag >= 0.5 ppm
Mo >= 10 ppm
Cu >= 1000 ppm
Au >= 0.3 ppm

Core
Outward

9,240,500 N
9,241,000 N
9,241,500 N
3,400 V
3,600 V
3,800 V

250 meter

Fig. 50
LEGEND

- Explosive Breccia
- Needle Hornblende Diorite
- Andesitic 'Lahar'
- Intramineral Granodiorite
- Main Productive Granodiorite
- Early Hornblende Diorite
- Limestone

Cone $500/Oz Au
Drill Holes
Fault

Fig. 51
Fig. 52
Fig. 53
Copper grade (ppm)

- 0.00 - 1000
- 1000 - 2000
- 2000 - 3000
- 3000 - 4000
- 4000 - 5000
- 5000 - 10000
- > 10000

Fig. 54
Silver grade (ppm)

- 0.005 - 0.150
- 0.150 - 0.300
- 0.300 - 0.550
- 0.550 - 2.030

Fig. 55
Molybdenite grade (ppm)

0.00 - 5.00
5.00 - 10.0
10.0 - 25.0
25.0 - 50.0
50.0 - 100.0
100.0 - 250.0
> 250.0

Fig. 56
Fig. 57
Fig. 58
Fig. 61
Fig. 62
Total Sulfide Distribution

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Fig. 63
ESTIMATED VOLUME % QUARTZ VEINS

- Blue: >= 1%
- Green: > 2%
- Red: > 10%
- Orange: > 20%
- Purple: > 30%

- Cone $500/Oz Au

Fig. 64
GEOCHEMISTRY ZONING

Ag >= 0.5 ppm
Mo >= 10 ppm
Cu >= 1000 ppm
Au >= 0.3 ppm
Zn >= 100 ppm
Pb >= 50 ppm

Fig. 65