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The La Cabeza Gold–Silver Deposit: A Low-Sulphidation Epithermal System in the Bloque de San Rafael, Mendoza, Argentina.

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ABSTRACT

La Cabeza gold-silver deposit, situated on the Bloque de San Rafael, Mendoza Province, Argentina, includes several prospects where mineralization lies within a variably dipping sequence of silica – sericite altered rhyolitic ignimbrites locally intruded by fine grained to medium grained felsic porphyries, all belonging to the Permo-Triassic Choiyoi Group. Gold mineralization occurs as free gold and electrum in iron oxides, silica and sulphides, all within quartz veins, quartz stockworks and siliceous jigsaw breccias close to or on the contact between rhyolitic ignimbrite and fine-grained porphyry. Mineralization is controlled by NW dextral brittle shear zones, E-W left lateral and extensional N-S extensional structures in a transpressive setting. La Cabeza is a silica-sericite-adularia low sulphidation epithermal gold ± silver system related to the emplacement of several intrusive phases potentially related with a relatively shallow level magmatic body.

INTRODUCTION

The La Cabeza Gold Project is located in the southeast of Mendoza Province, 180 km east of the city of Malargüe, in central western Argentina. The semi-arid weather and relatively flat topography allow all year-round access. It was discovered in 1996 by Argentina Mineral Development SA (AMD) while investigating potential hydrothermal alteration features outlined by Landsat TM imagery. The subsequent exploration at district scale resulted in the delineation of a significant and large zone of gold mineralization within a four square kilometre area hosted by altered felsic volcanics and sediments. Between January 1997 and December 1998 an intensive exploration programme consisting of geological mapping, rock geochemistry, airborne and ground geophysics was carried out on the prospect. The work resulted in a 16,070 metre drilling programme consisting of 126 reverse circulation percussion and diamond drilling holes. This exploration programme led to the definition of the current main areas of known gold mineralization within the La Cabeza Gold Project: La Luna, El Ojo, El Cuello, La Mandíbula, El Cachete and El Labio. Due primarily to the fall of international metals prices, AMD ceased further exploration activities in 1999. Exeter Resource Corporation (Exeter) acquired the properties in 2003.

At the end of 2003, a detailed programme commenced of infill and extension drilling (both diamond and reverse circulation percussion) and surface geochemistry at the four main prospects (La Luna, El Ojo, El Cuello and La Mandíbula) in order to provide sufficient density and confidence to lift previously defined Inferred Resources amenable to open pit mining to Indicated Resource status. By the end of February 2005, 4,798 metres of diamond and reverse air circulation percussion drilling totalling 67 holes was completed which included an additional 2,050 metres of sawn channel sampling.

At the beginning of 2005 international consultants, Hellman and Schofield Pty Ltd, prepared revised resource estimates for La Luna, El Ojo, El Cuello and La Mandíbula. Gold grade estimation was performed using Multiple Indicator Kriging. Exeter personnel provided updated resource estimates (where appropriate) for El Cachete, Labio East, South and West prospects. This work delineated, at a cut-off of 0.5 g/t Au, an Indicated Mineral Resource of 6.2 Mt grading 2.0 g/t Au totalling 390,000 ounces of gold, and an Inferred Mineral Resource of 12.1 Mt grading 1.3 g/t gold totalling 500,000 ounces of gold, according to CIM Mineral Resources and Mineral Reserve Definitions.

The aim of this paper is to show relevant information related to the main prospects at La Cabeza such as hydrothermal alteration, structural setting, mineralisation details and to discuss the genetic model derived from the interpretation of the data mentioned above.

REGIONAL GEOLOGY AND TECTONIC SETTING

The basement rocks of the region consist of Pre-Cambrian meta-sediments belonging to the greenschist and amphibolite facies which are unconformably overlain by a marine sedimentary sequence, Carboniferous in age, consisting of quartz sandstones with interlayered black shales (equivalent to the Cerro Agua Negra Formation in the Cordillera Frontal as described by Rodriguez Fernandez *et al*, 1998). This unit is uncomformably overlain by the Permian-Triassic Choiyoi Group consisting

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of andesitic volcanics and volcaniclastics, dacitic to rhyolitic ignimbrites and associated felsic intrusives. The Choiyoi Group has been divided into two sections by Llambias *et al.* (1993) on the basis of the main lithological and geochemical characteristics: *The Meso-silicic Lower Section and the Felsic Upper Section.* The Lower Section (Lower Permian in age) is represented in the region by a mesosilicic volcanic and volcano-sedimentary sequence which is genetically related to the San Rafael Orogeny (Ramos 1998), during which a calc-alkaline magmatic arc evolved in the palaeo-Pacific Gondwana border between the Upper Carboniferous and the Lower Permian (Davidson and Mpodozis, 1991; Sillitoe, 1991). This rock unit is conformably overlain by the Felsic Upper Section (Upper Permian to Triassic in age) and consists of ignimbrites and rhyolite domes, andesitic dykes, mesosilicic to felsic sub-volcanics and alkaline basalts to andesites (Narciso *et al*. 2000). Compositional variations between both sections show the transition from a calc-alkaline arc magmatic orogenic regime related to an un-orogenic extensional regimen (Sato and Llambías, 1993). These rocks are intruded by coeval granites and by NW to N trending felsic dykes of probably Permian age with geological correlations to similar dykes in the Cordillera Frontal (Cegarra, 1998).

Tertiary to Quaternary basaltic flows associated with several volcanic cones cover large areas to the north and west of the project area in the Payunia region. Quaternary alluvial deposits, which are currently filling flood plains and small valleys, complete the stratigraphic setting.

Dominant structures are principally in NW, N and NE orientations. The rocks of the region dip approximately to conforming open-folds bordered by NW faults. The position of the stratigraphic units suggest a pure extension early structural activity and reverse reactivation for the NW structures, similar to other regions dominated by the Gondwana magmatism such as the Cordillera Frontal.

LOCAL GEOLOGY

The La Cabeza basement consists of Carboniferous quartz sandstones interbedded with black shales, which are unconformably overlain by the Choiyoi Group rocks whose lower section is represented at district scale by thin beds of volcaniclastic crystal sandstone. Gold mineralization is hosted by felsic volcanics of the Choique Mahuida Formation (Narciso *et al*., 2000) belonging to the upper section of the Choiyoi Group. This unit consists of felsic ignimbrites, pyroclastic rocks and crystal-vitric tuffs, locally intruded by fine to medium grained felsic porphyritic rocks with occasional oriented phenocrysts. From surface mapping and drilling this unit dips predominantly to the NW, however in the vicinity of folding, which trends sub-parallel to the main NW structures, dips to the NE and SW are observed. Whole rock K/Ar age dating for this felsic unit ranges from 266 to 215 ± 10 Ma (Linares, 1977; 1979).

The Don Sixto Breccia, a conspicuous lithological unit of the deposit, is a fragmental rock formed by variable siliceous to sericitic altered felsic volcanic clasts with minor sediments and quartz vein fragments. The brecciation process is interpreted as hydraulic fracturing controlled by NW brittle shearing.

Numerous NW and N trending barren felsic dykes are located in the region intruding the Permian and Triassic volcanic-sedimentary units.

TYPES OF DEPOSITS AND STYLES OF MINERALISATION

Four main styles of mineralization controlled by the structural setting, fluid pressure and hydrothermal alteration have been identified:

1. Quartz veins emplaced in brittle shear zones which are controlled by NW dextral strike-slip faulting with subordinate EW conjugated structures dipping 60º-75° to the NE. This style of quartz veining is an important feature of mineralization observed at the La Luna, La Mandíbula and El Cachete prospects;

2. Pure extensional quartz veins filling N-S and NNE-SSW structures and dipping 60-80°. This style is observed at El Cuello and El Labio prospects;

3. Quartz veins which are sub-parallel to the ignimbrite bedding planes. These veins are NW trending and dip gently to the SW. This style is observed at the La Luna and El Cachete prospects;

4. Zones of stockworking and hydraulic fractured brecciation with a chalcedonic silica matrix. These textural fabrics are mainly controlled by up-rising hydrothermal fluid pressure related with NW brittle shearing zones. This style is observed at the La Luna, La Mandíbula and El Ojo prospects.

The veins are massive or display crustiform-coliform banding with textural and mineralogical boiling indicators such us adularia and/or bladed calcite replaced by silica. The veins are generally characterised by pinching and swelling with true widths between 2 metres to 21 metres at El Cuello prospect.

The main prospects are as follows:

El Cuello

This prospect consists of three sub-parallel quartz veins that pinch and swell, dipping 65-75° E and with widths varying between 1.5 metres to 21 metres. These veins are hosted by ignimbrites or emplaced in the contact between ignimbrite and felsic porphyries.

A mineralized hydrothermal breccia with sub-angular silicified fragments and a fine-grained siliceous matrix was observed occasionally at depth in drilling.

Hydrothermal alteration forms haloes around the veins and it is characterized by host rock silicification, siliceous

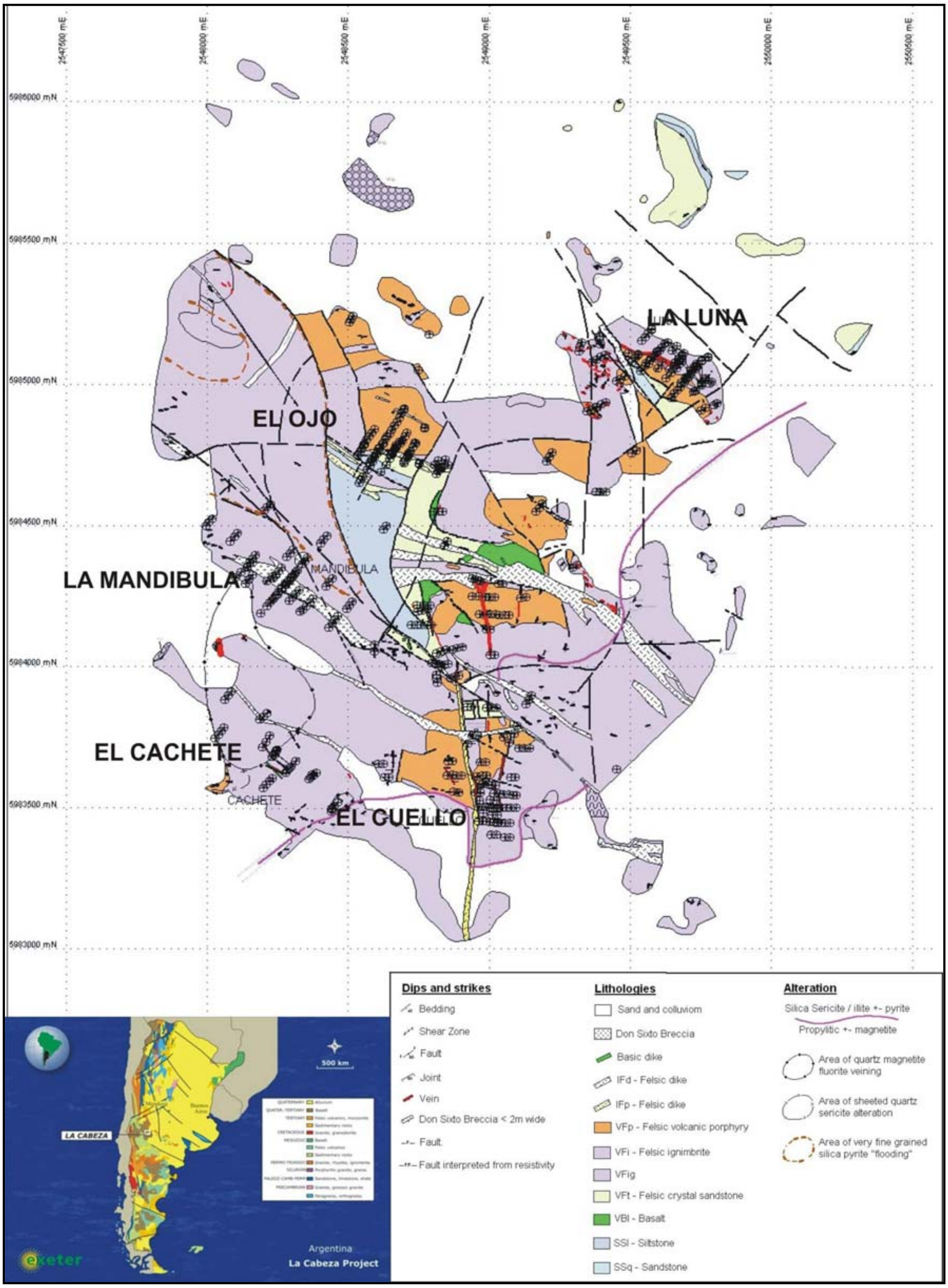

Figure 1. Geology, structure and hydrothermal alteration of the La Cabeza Deposit at 1250 metre R.L. (from Roger Poltock)

stockworks, open-space filling and sericite replacing feldspars.

El Ojo

Gold mineralization at this prospect is related to hydraulically fractured breccias with a grey chalcedonic-silica matrix. Clasts display partial to total destruction of the original texture and mineralogy. Other mineralized zones are characterized by chalcedonic and dark grey silica (pyrite and arsenopyrite-rich) hosted by fine-grained felsic porphyry rocks and quartz sandstones in the vicinity of a NW trending barren felsic dyke.

La Luna

Three *en-echelon* mineralized zones are interpreted at this prospect consisting of banded quartz veins, stockworks, jigsaw brecciation and strong silicification controlled by NW structures. Two of these zones dip between 60° and 80° NE and the third one is sub-parallel to the ignimbrites bedding planes and dips gently to the SW. Fine-grained felsic porphyry and ignimbrite are the host rocks with the highest gold grades related to the contact zone between both of these lithologies, in the upper part of felsic porphyry or in the basal section of the ignimbrite.

La Mandíbula

This prospect is situated on a silicified ridge consisting of felsic ignimbrites and the Don Sixto Breccia unit for a strike length of 1100 metres. The volcanics are characterized by phenocrysts (feldspars, quartz), lithic fragments and fiammes in an aphanitic ground-mass. At depth, hornfelsed contact metamorphism (cordierite, biotite, phlogopite) and potassic feldspar veining were observed in the sedimentary rocks and felsic ignimbrites.

Two gold mineralized brecciation pulses have been differentiated at the prospect. Contact relationships indicate firstly a hydraulic-fractured brecciation pulse characterized by a dark grey silica cement and a second later stage related to the Don Sixto Breccia formation, characterized by low temperature silica and hypogenous hematite.

High grade gold mineralization related to a grey chalcedonic silica matrix was intercepted in drilling and channel sampling within the Don Sixto Breccia. Two styles of veins and stockworks related to NW brittle shear zones are observed at La Mandíbula:

1. banded quartz veins and veinlets with adularia, bladed calcite replaced by silica and comb quartz and;

2. massive grey chalcedonic veins with low grade mineralization. They dip 60-70º to the NE with an length of up to 800 metres.

El Cachete

This prospect includes all of the quartz veins located to the SW of La Mandíbula within an area of approximately 600 metres by 300 metres. These veins are controlled by NW brittle shearing and strike NW and E-W, dipping 45-55º SW. The maximum width observed is approximately 2 metres. Mineralogically they are characterized by quartz, magnetite, chlorite, fluorite and amphiboles.

The host rock is a thick sequence of felsic ignimbrites with haloes around the veins of silica, sericite and fine-grained disseminated pyrite.

Other prospects currently being further investigated at La Cabeza are Mercedes, Labio, Barbilla and Oreja.

The semi-circular distribution of the main prospects at La Cabeza is possibly connected to propagation structures, sub-circular in shape, interpreted to be related to the emplacement of a felsic to intermediate magmatic body at depth.

MINERALISATION

Mineralization at La Cabeza consists of gold with subordinate silver and traces of base metals hosted in veins, breccia, silicified structures and silica stockworks.

Polished sections of samples from La Luna, El Ojo and El Cuello (Townend, 2005) demonstrate sulphides hosted in varying styles of silica and also in the wall rock with concentrations ranging between 1 and 2 %.

At El Ojo prospect, the main sulphides observed are pyrite in the wall rock and pyrite, ±arsenopyrite in the siliceous gangue. Traces of chalcopyrite, marcasite, covellite, blue covellite and rutile have been observed in siliceous veins and breccias.

Oxidation is dominated by hematite and goethite formed after pyrite and arsenopyrite. Gold mineralization is characterized by native gold and electrum included in silica, pyrite and goethite.

At Luna, mineralization is characterized by pyrite, ±chalcopyrite, ±galena, pyrrhotite, marcasite and rutile. Oxidation is moderate in intensity and dominated by hematite, goethite and jarosite**.** Gold mineralization consists of free gold and electrum (47% silver) included in silica, pyrite and goethite.

At El Cuello prospect, the main sulphide is pyrite with minor arsenopyrite and traces of pyrrhotite, chalcopyrite, galena, chalcocite, blue covellite and rutile. Oxidation is moderate and is dominated by hematite and goethite formed after pyrite.

Gold can be observed in its native state and electrum included in sulphides (pyrite and arsenopyrite) and quartz. El Cuello is the most silver-rich prospect at La Cabeza. Silver is observed in its native state, electrum, galena and pyrargyrite.

STRUCTURE

The La Cabeza deposit was emplaced in the intersection of NW, NE, N and E trending structural systems regionally controlled by a first order NW transcurrent structure. Japas and Kleiman (2002) determined that the NW systems in the Bloque de San Rafael demonstrate evidence of early dextral transpressive kinematics followed by a left lateral transtensive reactivation as a consequence of the transition of the deformation regimen from compression (during the San Rafael Orogeny) to extension (Upper Felsic Section deposition).

Structure geometry and kinematics determined from surface mapping and drilling information suggest that the volcanic sequence hosted at La Cabeza might have been accumulated in a "pull-apart" basin controlled by NW structures. These structures were affected by two compressive deformation processes: the first (D1) as a result of a N to NNE sub-horizontal contraction and the second (D2) being formed during a post mineral NW contraction.

Geometric and kinematic information, cross-cutting relationships between structures, veins and brecciation types and hydrothermal alterations styles suggest that the mineralization was controlled by NW brittle dextral shears, associated with E-W left lateral and N-S pure extensional structures, with all them related to the D1 contraction event within a transpressional regimen (Coughlin, 2005).

GENETIC MODEL AND CONCLUSIONS

Epithermal systems are related to emplacement of a magmatic body exploiting the high permeability conditions created by a locally extensional structural setting.

The genesis of low sulphidation systems is controlled by the mixing between the rising magmatic fluids and the descending waters which circulate through extensional structures under near neutral pH conditions within the hydrostatic pressure environment (Hayba et al, 1985; White and Hedenquist, 1991). These physical-chemical conditions take place some distance from a heat and metal source. The boiling mechanism is a predictable consequence for circulating fluids exposed to high temperatures and low pressure conditions found in the environment. This is one of the main factors for precipitation of high concentrations of gold within the epithermal environment (Corbett and Leach, 1998; Hedenquist *et al*, 1991).

Information given in this paper demonstrates that the La Cabeza deposit is an epithermal low sulphidation silica-sericite-adularia system with Au ±Ag and traces of base metals. This system is composed of different mineralized-style deposits with all of them related to porphyry and felsic dyke phases in shallow crustal levels under a transpressional tectonic regimen.

The hydrothermal alteration zonation in the wall rock demonstrates progressive neutralization and a loss of temperature of the hydrothermal fluids when increasing the distance from the source area.

The sulphide mineralogy is consistent with theoretical chemical behaviour of the system. Banded fabric and textural and mineralogical boiling indicators (adularia and quartz pseudomorphs after bladed calcite**)** suggest that boiling could be an important mechanism in gold precipitation which is part of bisulphide complexes in this environment (Simmons and Browne, 2000) similar to silver. It could precipitate as native metal by bisulphide dissociations during the boiling process or co-precipitate with pyrite or arsenopyrite by a combination of H_2S and Fe^{2+} which is the most common iron species observed in low-salinity waters (Drummond and Ohmoto, 1985). Silver is chemically more active than gold and can form a wider range of minerals or replace metallic ions in other minerals such as galena, copper sulphides and sulfosalts.

Variations of style and mineral associations at each prospect are related to the balance between structural control and hydrothermal flow pressure, stratigraphy and distance from the heat and metal sources.

The geometry of the mineralized zones was altered by a post-mineral NW compressional event (D2). Development of hydrothermal breccias and stockworks along the fault zones implies that fluid pressure temporarily and locally exceeded the tectonic and lithostatic load.

Variations of mineralogical associations among the different prospects suggest that these reflect the different distances from the heat and metal sources. It is interpreted that due to the presence of magnetite and chlorite in quartz veining at El Cachete, potassium feldspar veining and hornfels evidence at deeper portions of La Mandibula and the more intense Cu, Mo and Sn anomalies, all indicate a closer proximity to a magmatic source towards the SW part of the deposit. Taking into account the main prospects, the semi-circular distribution of mineralization at La Cabeza is possibly related to circular structures potentially propagated by the intrusion of a main magmatic source at depth.

The composition of the very shallow intrusive facies suggests a similar composition to the potential main magmatic source at depth mentioned above. The fine-grained felsic porphyry unit is not observed in other parts of the district. The circular structures are not part of a caldera setting as no evidence of explosive volcanism (such as phreatic or phreatic-magmatic breccias) has been recognized at surface or in drilling.

Although radiometric ages are not available, it can be assumed that the deposit could be related to the gondwanic metallogenic phase due to the similarities to the geotectonic environment at the Cordillera Frontal where different mineralized systems hosted by the Choiyoi Group rocks and related to the San Rafael Orogeny (such as Casposo, Tocota and San Jorge) evolved.

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