

# Gold grain morphology and composition as an exploration tool: application to gold exploration in covered areas

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**ABSTRACT:** The results of research in the use of Au grain morphological and compositional properties applied in primary Au ore exploration are presented here. Two different and independent topics are discussed: (1) morphological characteristics of Au grains from active stream sediments for use as a distance-to-source indicator; (2) compositional signature of Au grains from various deposit types for use as a discrimination tool for source type and present deposit erosion level determination. The purpose of this study is to improve and integrate these two approaches as an exploration tool for Andean covered areas.

Au grain morphology for over 1500 nuggets recovered from 60 active stream sediment samples in the Coastal Cordillera of Central Chile shows morphological variations (general shape, outline, surface, primary crystal imprints, associated minerals, flatness index) characteristic of three distance ranges (0–50 m; 50–300 m; >300 m) from source. Comparison with results from other similar studies of Au morphology characteristics in different climatic and/or sedimentological environments (arid, semi-arid, wet, lateritic, fluvial, fluvio-glacial and glacial) resulted in the determination of the recommended parameters (outline, surface, associated minerals, flatness index) to be used as distance-to-source indicator, independent of the climatic and/or sedimentological environment.

Au grain morphological characteristics may assist in location of target but are not indicators of source type. Study of Au composition via electron microprobe analysis of Au grain cores from epithermal, Au-rich porphyry and Au-rich porphyry Cu systems indicated Au–Ag–Cu contents to be the best discrimination tool for these different types of Au-bearing deposits. In addition, such analysis of grains recovered at different vertical levels from the Cerro Casale Au-rich porphyry provides evidence that the Au compositional signature for a single type of deposit can also aid in the determination of vertical position. This may provide an estimate of the current level of erosion and remaining potential of the source. Some limitations of the proposed techniques are: (1) Au liberated from rock fragments already distant from source would be common in cordilleran and glacial environments, although this would be a detectable feature; (2) these techniques are applicable only for coarse-Au sources; (3) estimate of erosion level of liberated Au is limited to the case here presented.

**KEYWORDS:** *gold exploration, gold grain morphology, gold grain composition*

## INTRODUCTION

Au grains in primary or detrital ores, saprolites, soils or sediments have a characteristic morphology or micromorphology and composition. Native Au is a very malleable mineral and in a supergene natural environment Au grains are highly deformed during transport by contact with fragments of rock and/or hard minerals. The morphological transformations are a function of distance and environment of transport (Hérail 1984;

Averill & Zimmerman 1986; Giusti 1986; Averill 1988; Hérail *et al.* 1989; DiLabio 1991), and hence can provide information regarding travel distance with respect to source and information concerning transport mechanism and sedimentological environment. Au grains are a natural alloy of Au, Ag, Cu, etc. in proportions that vary with the condition of ore formation (Desborough 1970; Boyle 1979). This alloy is unstable in weathering conditions, an Ag-depleted rim being common around a preserved core (Desborough 1970; Hérail *et al.* 1990).

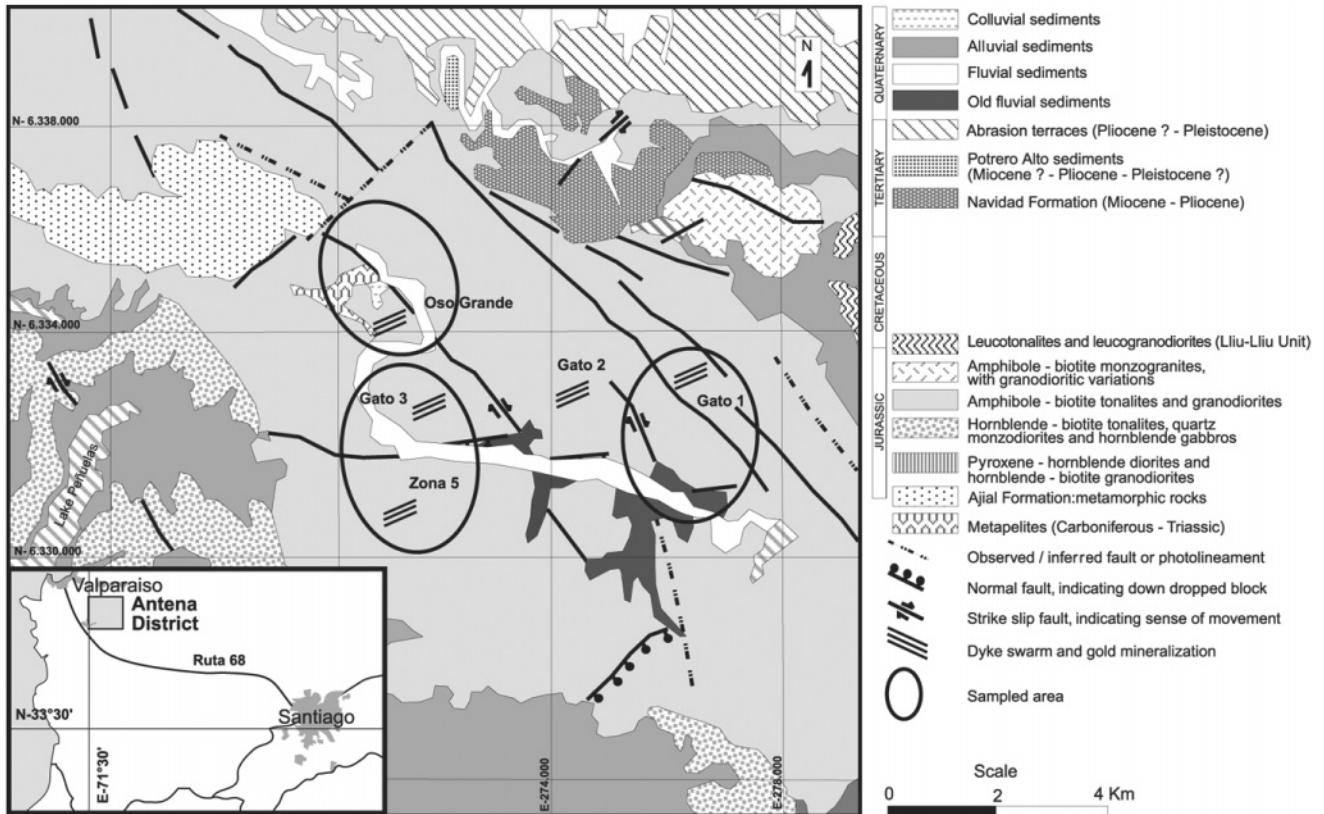


Fig. 1. Location, geology, Au source deposits (greissen altered dyke swarms) and sampled areas in the Antena District, Central Coastal Cordillera, Chile.

Thus, using a composition analysis of the Au grain cores it is possible to characterize the effect of weathering undergone by the Au grains in soils or sediments and the source in terms of deposit type (Guindon & Nichol 1982). Based on these properties, it is possible to use both, in conjunction, for the determination of distance-to-source and type of and present deposit erosion level of the expected source (Hérial *et al.* 1990; Grant *et al.* 1991).

Two main topics are presented in this study, independent one from the other: (1) Au morphology as a distance-to-source indicator; (2) Au composition as a discrimination tool for source type and, for a specific case, determination of present deposit erosion level. The purpose of this study is to improve and integrate these two approaches for different Andean geological environments. Together, these may become a useful tool for exploration in covered areas, allowing backtracking to source and source evaluation in terms of deposit type and present deposit erosion level.

#### GOLD GRAIN MORPHOLOGY AS A DISTANCE-TO-SOURCE INDICATOR

The use of stream sediment recovered Au grain morphological characteristics as a distance-to-source indicator is presented for the Antena District case (Chile), in which three years of research resulted in the determination of near-source Au morphological characteristics allowing short-range determinations (within 1 km). Comparison of these results with conclusions from other studies, some of them from our research group, allowed the determination of common distance indicators from Au morphological characteristics within different climatic and/or sedimentological environments. Hence, a methodological tool is proposed for estimating distance-to-source of nuggets in Au exploration.

#### The Antena District case

The Antena District is located within the central Coastal Cordillera of Chile, V Region, *c.* 100 km NW of the city of Santiago and 18 km from the main port of Valparaiso, at a mean elevation of 250 m (Fig. 1). The district has a long history of placer Au mining, dating back to colonial times (Cuadra & Dunkerley 1991).

Rocks within the district comprise Carboniferous–Triassic metapelites, intruded by Upper Jurassic biotite–amphibole tonalites and granites (162–150 Ma; Gana *et al.* 1996; Fig. 1). These rocks are intruded by dioritic to granitic stocks and dykes with an associated greissen-type alteration and Au mineralization. Faults, observed and inferred, form a conjugate N40°–60°W and N30°–50°E pattern, with lesser east–west faults. Greissen altered and mineralized dyke swarms are spatially associated with the NE-trending faults. Morphologically the district is characterized by low rolling hills cut by a dendritic drainage system. The weathering profile consists of a deep (30–15 m) Fe-rich saprolite. Rock outcrops are scarce, mostly affected by strong weathering. Active stream sediment bulk sampling (1 m<sup>3</sup>) in the Antena District, washed and concentrated for heavy minerals, yielded physical recovery of Au grains. The use of mechanical concentrators (Knelson and Gold Screw) yielded 3–6 samples per day. The use of expert native hand panners allowed recovery of about 12 samples per day, with lower water consumption and less cost. A total of 60 samples were taken (Fig. 1), from which 1502 Au grains were recovered. These Au grains were studied under binocular lenses and by scanning electron microscopy. The purpose was to measure their dimensions and characterize their morphology. Evidence of Au recrystallization was not observed. Size range for grains is 0.01–5.3 mm (Fig. 2). Based on morphological characteristics, shape, outline, sur-

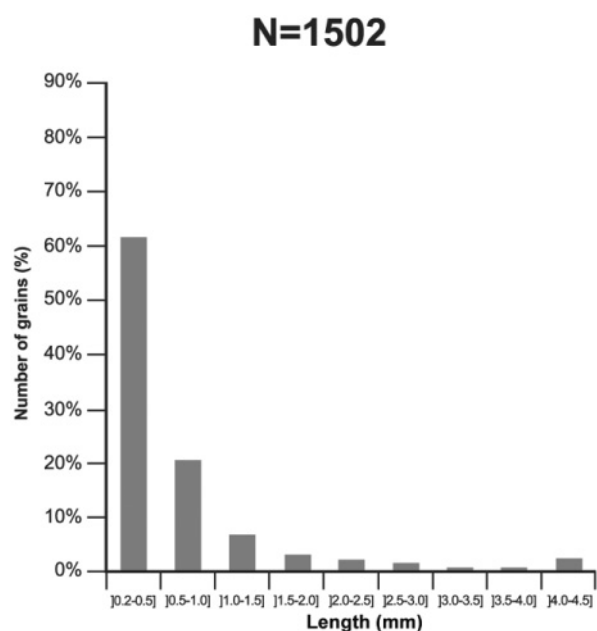


Fig. 2. Au grain length size histogram for samples from the Antena District.

face, associated primary crystal imprints, mineral inclusions and flatness index (defined as  $(L + b)/2t$ , where  $L$  is length,  $b$  is breadth and  $t$  is thickness), three main Au grain groups were determined (Table 1).

The first group is represented by Au grains recovered between the source (dyke swarms) and 50 m downstream. Within this range, Au grains have retained their original shape with respect to the source: square to rectangular shapes, angular edges and with embayments. The general outline of grains is irregular, with rugged topographical surfaces. These grains

normally have associated primary crystal imprints, commonly with inclusions of quartz and/or Fe oxides. The flatness index of Au grains ranges between 1 and 3.6.

Au grains recovered between 50 and 300 m downstream from the source represent the second group. Within this range, Au grains have triangular to slightly elongated shapes, and to a lesser degree, angular. Outline is relatively regular, with some evidence of folding. Surface topography is irregular and vugs are a common feature on grains. Primary mineral imprints are diffuse and associated minerals consist only of iron oxides (rare). Flatness index ranges between 2.1 and 6.

Au grains recovered over 300 m downstream from source represent the third group. These grains are rounded to oval, in many cases elongated. Outline is regular and surface topography tends to be smooth. Impact and groove marks are common. Primary mineral imprints are absent and associated minerals consist only of limonite or clay coatings. Flatness index ranges between 3.0 and 7.5.

A group of Au grains within any specific distance range will be representative of their distance-to-source only if the group represents a single statistical population. Population statistical analysis generally requires at least 20 data points. Hence, for determination of a valid distance range from Au morphological characteristics, it is recommended that at least 20 Au grains for each distance range be studied and measured. Flatness index must be measured for all grains, as it represents the only numerical parameter amenable to a population statistical analysis.

#### Comparison with other environments and distance-to-source indicator parameters

From the previously presented study case and many others (indicated below), the use of Au grain morphology evolution as a function of travel distance from source has been demonstrated, representing an effective exploration tool in the

Table 1. Morphological characteristics of Au grains associated with distance from source

Distance to the source	0-50 m	50-300 m	> 300 m
<b>General shape</b>			
<b>Outline</b>			
<b>Surface</b>			
<b>Primary crystal imprints</b>		Diffuse Evidence	Absent
<b>Associated minerals</b>	Quartz and Fe Oxides 	Fe Oxides 	Limonites 
<b>Flatness index</b>	1-3.6	2.1-6	3.0-7.5

Table 2. Morphological characteristics of Au grains associated with distance from source in different climatic and/or sedimentological environments

Physical Characteristics of the Gold Particles		Distance to the Source			
		0-50 m	50-300 m	300-1000 m	>1000 m
Outline	Regular				
	Very regular				
	Very irregular				
	Polished				
	Bent-up				
	Folded				
Surface	Regular topography				
	Irregular topography				
	Hammered				
	Impacts				
	Grooves				
	Cavities				
Associated minerals	Clay and Fe hydroxides				
	Quartz				
	Fe oxide-Pyrite				
	Primary imprints				
<b>Flatness index</b>		<b>1-3.0</b>	<b>2.1-4.6</b>	<b>3.0-8.6</b>	<b>4.0-16.0</b>

Never present (0%)
  Occasionally present (less than 50%)
  Always present (over 50%)

identification of proximity to Au deposits. From the exploration perspective it is necessary to have and define specific Au morphological distance-to-source indicator parameters that are independent of climatic and/or sedimentological environments. Thus, the morphology of Au grains as a function of distance-to-source was compared for various climatic and/or sedimentological supergene environments, such as arid, semi-arid, humid, lateritic, fluvial, fluvio-glacial and glacial.

By comparison of Au grain morphology from different environments in Chile, Bolivia, West Africa and Canada, four travel distance ranges were defined. The main common morphological characteristics defined for each range and environment are as follows (Table 2).

(1) Au grains recovered between source and 50 m downstream. This group included analysis of Au grains from: (a) weathered Au veins in lateritic soils and active sediments in Meroi, Ivory Coast (Grant *et al.* 1991); (b) tills from Waddy Lake, Canadian Shield (Averill & Zimmerman 1986); (c) weathered Au veins and sediments in saprolite from the Antena District, central Chile; (d) arid and semi-arid alluvial environment from northern Chile (Lagos 1996; Varas 1996; Hérail *et al.* 1999). These grains have retained their original general shape: square to rectangular, irregular star, very angular and partially embayed. Grain outline is very irregular, with an irregular surface topography. These grains commonly show primary mineral imprints and inclusions of quartz, Fe oxides and/or pyrite. Flatness index ranges between 1 and 3 (cases (c) and (d)).

(2) Au grains recovered between 50 and 300 m downstream from source. This group was defined based upon the following data: (a) glacial terrains from Owl Creek, Ontario and Waddy Lake, Canadian Shield (Averill & Zimmerman 1986; Grant *et al.* 1991); (b) saprolitic environment from the Antena District, central Chile; (c) arid and semi-arid alluvial environment from northern Chile (Lagos 1996; Varas 1996). In this distance range, Au grains have irregular angular shapes, regular outline and surface topography, and frequently contain quartz inclusions. Flatness index ranges from 2.1 to 4.6 (cases (b) and (c)).

(3) Au grains recovered from 300 m to 1 km downstream from source. Data used for the definition of this distance range are: (a) tills and glacial environment from Waddy Lake, Canadian Shield (Averill & Zimmerman 1986); (b) saprolitic environment from the Antena District, central Chile; (c) arid and semi-arid alluvial environment from northern Chile (Lagos 1996; Varas 1996). The great majority of grains in this distance range have a rounded to oval shape, commonly elongated. Outline and surface topography is regular, sometimes hammered and with folded edges. Flatness index ranges between 3 and 8.6 (cases (b) and (c)).

(4) Au grains recovered over 1 km downstream from source. Data compilation for this distance range was obtained from: (a) glacial terrains from Waddy Lake, Canadian Shield (Averill & Zimmerman 1986; Grant *et al.* 1991); (b) lateritic environment, Laoudi, Ivory Coast (Grant *et al.* 1991); (c) alluvial environment in Tipuani, Bolivia (Hérail *et al.* 1990); (d) fluvio-glacial environment from southern Chile (Ordoñez 1998); (e) arid and semi-arid alluvial environment from northern Chile (Lagos 1996; Varas 1996). These grains have a rounded and oval shape, with a very regular, smooth and polished outline and surface topography, commonly exhibiting striations and impact marks, and a hammered appearance. Flatness index ranges from 4 to 16 (cases (c), (d) and (e)).

Considering the characteristics of Au grain morphology in different climatic and/or sedimentological environments downstream from a primary source, common characteristics with respect to distance range are defined in Table 3. These parameters are those recommended for use as an Au exploration tool, following a systematic description of Au grains recovered from active stream sediments.

#### GOLD GRAIN CORE COMPOSITION AS AN INDICATOR OF SOURCE DEPOSIT TYPE AND PRESENT DEPOSIT EROSION LEVEL

Native Au can be in complete solid solution with native Ag and partially with Cu, Fe, As and Bi, amongst others. The



**Table 3.** Common features in Au grains from different climatic and/or sedimentological environments

Distance range (m)	Contours	Surface features	Mineral inclusions	Flatness index
0–50	very irregular	irregular, primary mineral imprints	Quartz, iron oxides and pyrite	1.0–3.0
50–300	regular	regular	quartz	2.1–4.6
300–1000	regular	hammered, folded edges	–	3.0–8.6
>1000	very regular and polished	impact marks and striations, hammered	–	4.0–16.0

composition of hydrothermal Au depends on the thermodynamic conditions of transport and precipitation and on the total metal budget of the system (Morrison *et al.* 1991; Gammons & Williams-Jones 1995; Rubin & Kyle 1997). These thermodynamic conditions and metal budget differ from one type of hydrothermal deposit to another, and hence different deposit types will each have a characteristic Au compositional signature.

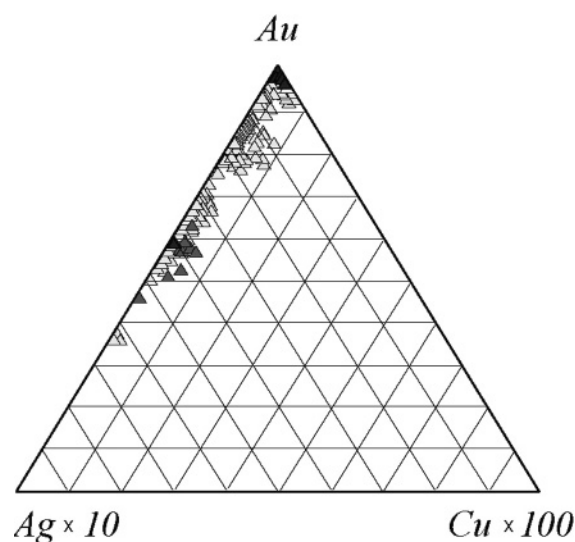
Active stream sediment Au grain composition may indicate the type of deposit from which the grains have been eroded. Considering that the core of Au grains recovered from active sediments retains the original composition characteristic of its source hydrothermal system (Groen *et al.* 1990; Héral *et al.* 1990), the compositions of Au grains from epithermal, Au-rich porphyry and Au-rich porphyry Cu systems have been analysed and compared, with the objective of attempting a discrimination model among these different types of hydrothermal environments. Additionally, a discrimination model for Au composition variation with respect to alteration and vertical position within an Au-rich porphyry (Cerro Casale) allows, in that particular case, a tool for estimating the present deposit erosion level.

#### Source type determination: epithermal, Au-rich porphyry and Au-rich porphyry Cu deposits

In this specific study the epithermal environment is represented by samples from Guanaco and Pimentón, north and central Chile, respectively (21 grains), and samples from south-central Bolivia (Alarcon & Fornari 1994; Ramos & Fornari 1994). The Au-rich porphyry system is represented by the Cerro Casale deposit, Maricunga, northern Chile (176; Palacios *et al.* 2001). The Au-rich porphyry Cu system is represented by Au from Grasberg, Indonesia (11 samples; Rubin & Kyle 1997) and the Santo Tomás II porphyry, Philippines (10 samples; Tarkian & Koopmann 1995).

Au grain cores (cut and polished) from our study (including those reported by Palacios *et al.* (2001)) were analysed by a CAMECA SX50 electronic microprobe at the University of Toulouse, France. A total of six elements were determined with WDS (Wavelength-Dispersive Spectrometer): Fe, Cu, As, Ag, Au and Bi. All samples were observed by back-scattered imaging electron microscopy (BEI); no significant compositional zonations were observed as confirmed by BEI and chemical analysis.

Composition analysis of Au showed Ag and Cu contents as the most useful discrimination elements (contents of other elements were too low). A ternary Au–Ag–Cu diagram shows significant compositional differences among Au crystals from the various deposits (Figs 3–6). Au crystals from epithermal environments have a low Cu content and tend to be Ag-rich (Fig. 3). Au-rich porphyry Cu associated Au crystals have a high Cu content and variable Ag contents, defining a well-differentiated area (Fig. 4). Au crystals from Au-rich porphyries are low in Cu contents and richer in Ag contents compared with epithermal environments, exhibiting a pattern of higher Cu contents with higher Au contents (Fig. 5).



#### Gold-rich epithermal deposits.

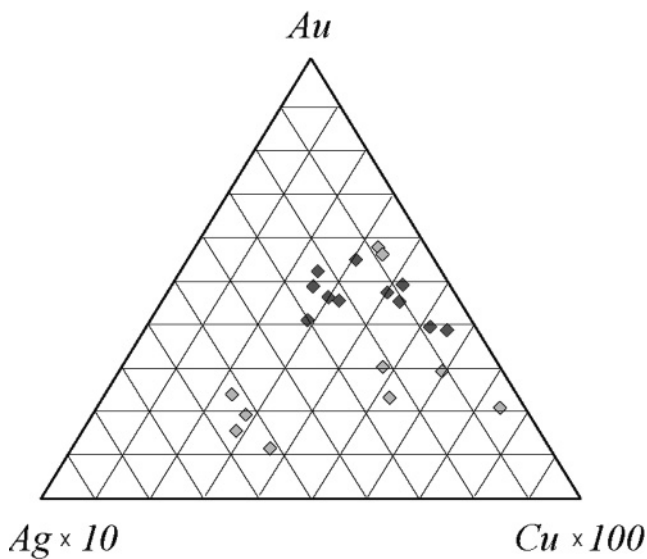
- ▲ Guanaco orebody, northern Chile (n=9)
- ▲ Pimentón ore deposit, central Chile (n=11)
- △ Ore deposits from Bolivia (n=249)

**Fig. 3.** Au–(Ag × 10)–(Cu × 100) compositional diagram for epithermal deposits.

The compositional analysis of Au crystals from different types of hydrothermal deposits suggests the Au–Ag–Cu ternary system as an appropriate discrimination tool for epithermal, Au-rich porphyry and Au-rich porphyry Cu systems (Palacios *et al.* 2001; Fig. 6). Additional study is necessary to verify and increase the number of deposit types, but these results offer a preliminary discrimination technique for the deposit types mentioned, especially useful for covered areas along metallogenic belts in which these types of deposits occur.

#### Gold source present deposit erosion level: the Au-rich porphyry case

As Au composition is a function of the thermodynamic conditions under which it is precipitated, the composition of Au would also be dependent on associated alteration types and on vertical and horizontal zonations. This hypothesis was tested by the study of Au composition associated with different lithological and alteration types (Palacios *et al.* 2001) and the vertical zonation of Ag and Cu in Au (this study) from the Cerro Casale deposit, Maricunga, northern Chile.



#### Gold-rich copper porphyries.

- ◆ **Grasberg, Indonesia**  
(Rubin, J. & Kyle, R., 1997; n=11)
- ◆ **Sto. Tomás II, Philippines**  
(Tarkian, M. & Koopmann, G., 1995; n=10)

Fig. 4. Au-(Ag × 10)-(Cu × 100) compositional diagram for Au-rich porphyry Cu deposits.

#### Cerro Casale gold porphyry, northern Chile (n=180).

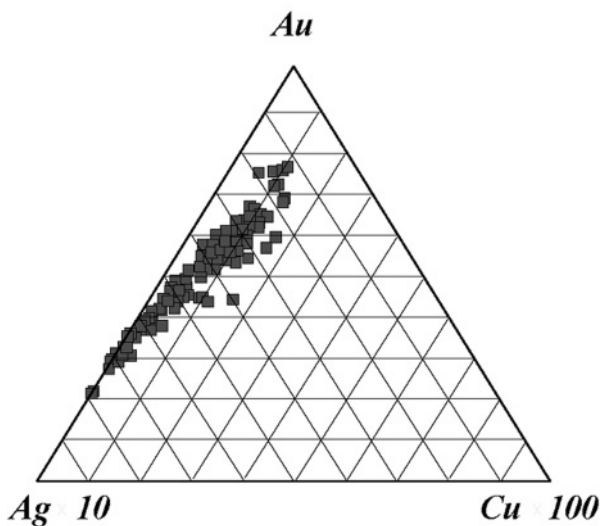


Fig. 5. Au-(Ag × 10)-(Cu × 100) compositional diagram for Au-rich porphyry deposit.

*Au composition as a function of lithology and alteration.* The Au-rich Miocene Cerro Casale porphyry occurs within altered and mineralized granodioritic and dioritic subvolcanic stocks, and within igneous-hydrothermal breccias, all hosted by Miocene volcanic rocks (Fig. 7). The deposit has a columnar shape with an approximately circular section some 500 m in diameter, and a vertical extension of over 1000 m. Resources are estimated at 800 Mt at 1 g t<sup>-1</sup> Au and 0.15–0.30% Cu (≈ 20 million ounces

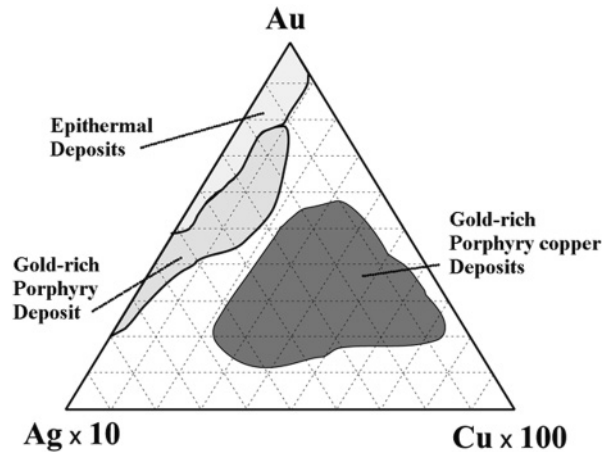


Fig. 6. Au-(Ag × 10)-(Cu × 100) compositional discrimination diagram for epithermal, Au-rich porphyry Cu and Au-rich porphyry deposits.

Au). Intrusive rocks include an equigranular textured hornblende granodioritic porphyry cut by a microdioritic porphyry. Igneous and hydrothermal breccias are located at upper levels of the system and along the contact between the two porphyries, and crop out at the surface (Palacios *et al.* 2001; Fig. 7).

A core of potassic alteration occurs at depth, surrounded by a chlorite-sericite halo, both associated with native Au mineralization (5–20 μm) observed mainly within quartz (Palacios *et al.* 2001). The early potassic association consists of biotite, K-feldspar, magnetite, hematite, quartz and anhydrite, with Au mineralization. An extensive magnetite, hematite, Au stockwork is associated with the potassic core. Fluid inclusion homogenization temperatures from these stockwork veinlets indicate values of about 500 °C with salinities between 40 and 50% NaCl equivalent. Peripheral chlorite-sericite alteration is overprinted on the potassic alteration, characterized by quartz, sericite, chlorite, pyrite, chalcopyrite and Au in veinlets and disseminations. Fluid inclusions in quartz from this association indicate temperatures in the range of 200–260 °C, with salinity values between 6 and 15% NaCl equivalent. Early igneous and hydrothermal breccia pipes in the central portion of the deposit include angular fragments of mineralized porphyry within a potassic alteration dominated matrix. Late hydrothermal breccias occur within the uppermost portion of the deposit and include angular fragments of the mineralized porphyry within a sericite, quartz, chlorite, tourmaline, chalcopyrite, pyrite, Au mineralized matrix.

The compositional study of Au in the Cerro Casale deposit indicated the following results (Palacios *et al.* 2001).

(1) Ag and Cu are the elements that show the strongest compositional variations in relation to lithology and hydrothermal alteration (Figs 8 and 9).

(2) Au crystals associated with potassic alteration show high Ag (8–28%) and low Cu concentrations (0–0.24%; Figs 8 and 9). Au compositions of crystals deposited within these early stages of mineralization differ between the granodiorite and the microdiorite (Figs 8 and 9): (a) Au crystals from the microdiorite have higher Ag (17–28%) and lower Cu (0–0.07%; Figs 8 and 9) concentrations; (b) Au crystals recovered from the granodiorite show lower Ag (7–17%) and higher Cu (0–0.24%; Figs 8 and 9) contents. The data indicate the existence of an Au compositional zonation as a function of hosting lithology and suggest that Au associated with potassic alteration is related to the microdioritic intrusion.

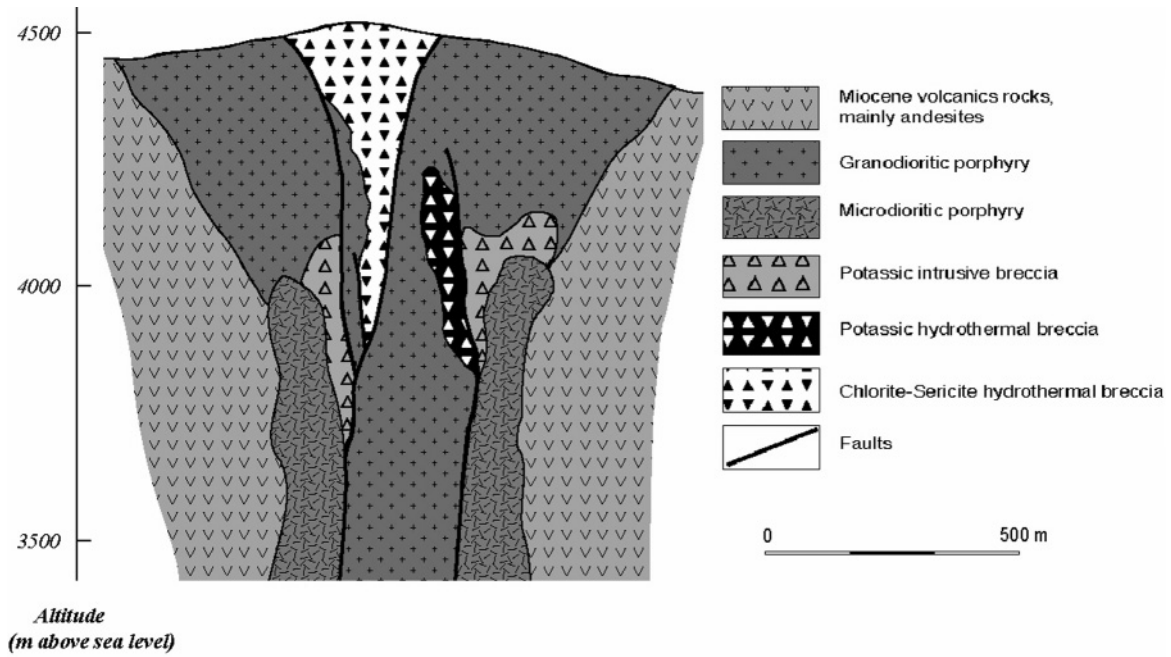


Fig. 7. Schematic cross-section of the Cerro Casale Au-rich porphyry deposit, Maricunga belt, Chile.

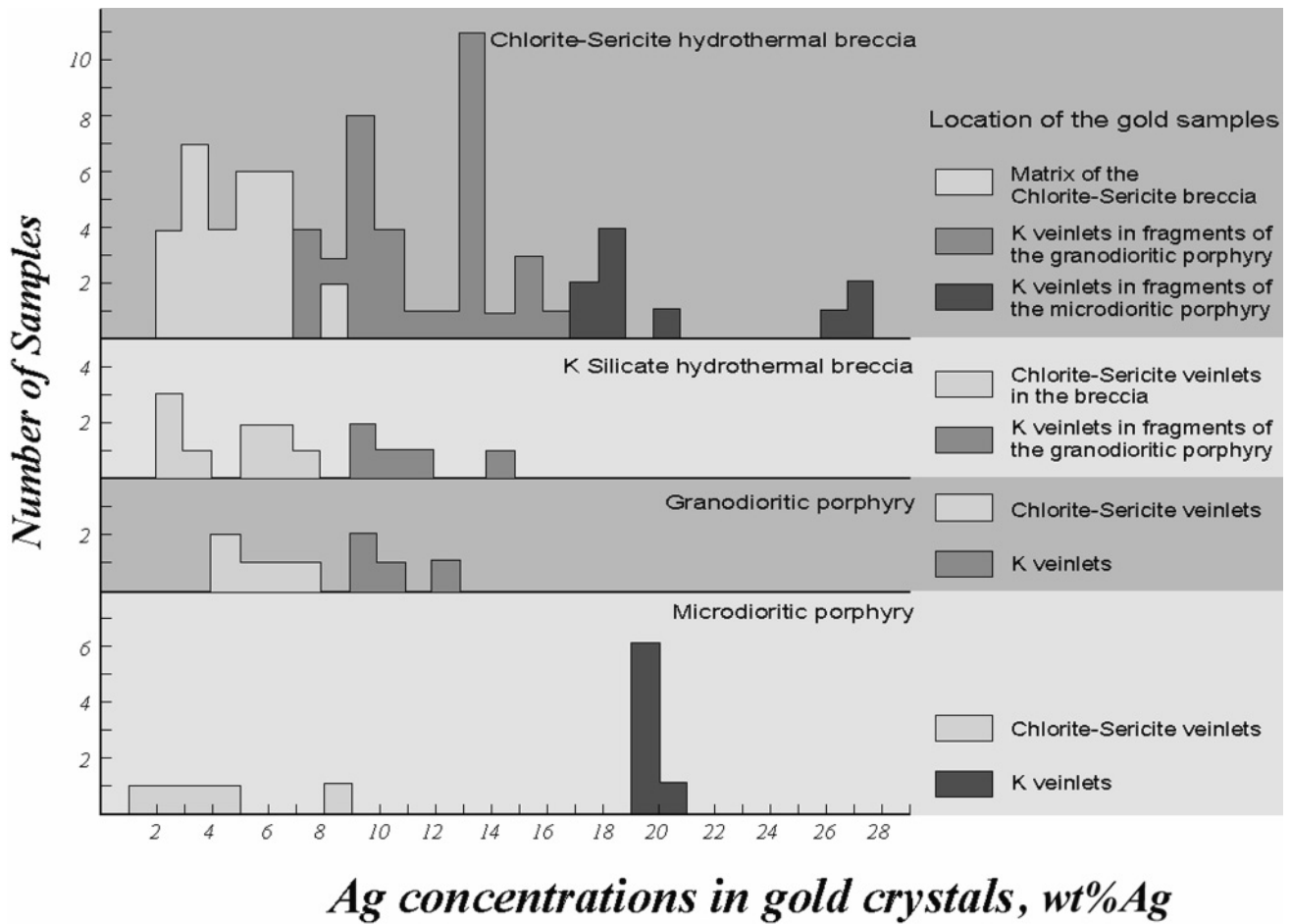


Fig. 8. Ag concentration in Au with respect to alteration and lithological types in the Cerro Casale Au-rich porphyry deposit.

(3) Au deposited during the chlorite-sericite alteration stage shows low Ag concentrations (1–9%) and relatively high Cu concentrations (0.06–0.34%; Figs 8 and 9).

(4) Au from hydrothermal quartz-sericite matrix breccia fragments retains the same composition with respect to lithology and alteration type of the respective fragment (Figs 8 and 9).

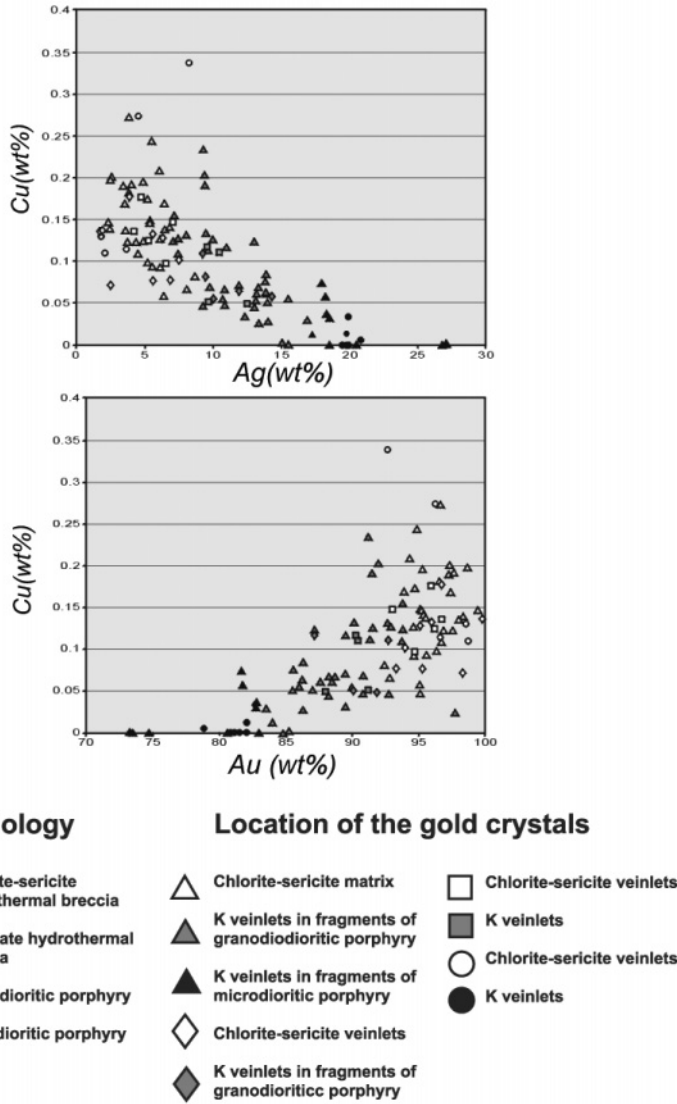


Fig. 9. Cu–Ag and Cu–Au diagrams with respect to alteration and lithological types in the Cerro Casale Au-rich porphyry deposit.

*Vertical zonation of Au composition.* The Cerro Casale deposit is fully preserved, with a vertical section of over 1000 m. A total of 116 Au crystals were analysed by microprobe from a vertical section of about 700 m. Data from Au recovered from breccia fragments were not considered as these represent material transported from depth. Figures 10 and 11 show Ag and Cu compositional variations in Au crystals with respect to vertical elevation. The concentration of Ag in Au associated with potassic alteration shows a progressive decrease from 19–21% in the deepest portions of the deposit (3400 m) to 7–16% in the highest parts of the deposit (3900 m; Fig. 10). In contrast, Ag in Au associated with sericite–chlorite alteration remains within the range 1.6–8.5% along the full vertical extent of the deposit (Fig. 11). The concentration of Cu in Au associated with potassic alteration does not vary notably with respect to elevation, within the range 0.02–0.18% (Fig. 10). The concentration of Cu in Au associated with sericite–chlorite alteration decreases progressively from 0.24–0.33% at 3350 m to 0.05–0.12% at the elevation of 4.025 m (Fig. 11).

The results of this study show that the concentrations of Ag in Au associated with potassic alteration and Cu in Au associated with chlorite–sericite alteration decrease progressively from depth to surface. The concentration of Ag in Au from an Au-rich porphyry environment allows discrimination between potassic alteration associated Au (8–28%) and

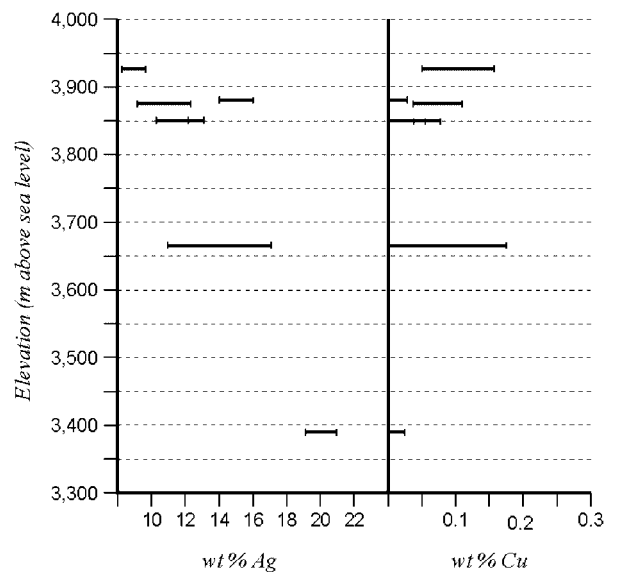


Fig. 10. Vertical zonation of Ag and Cu in potassic alteration associated Au, Cerro Casale.



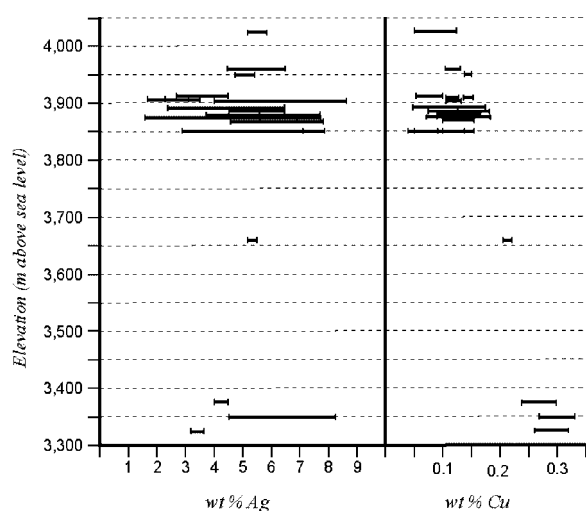


Fig. 11. Vertical zonation of Ag and Cu in chlorite-sericite alteration associated Au, Cerro Casale.

chlorite-sericite associated Au (1–8%). The concentration of Cu in Au associated with the same chlorite-sericite alteration allows an estimate of the current erosion level of the deposit, and hence the remaining exploration potential of the target. In summary, Ag content allows determination of chlorite-sericite alteration associated Au, and the Cu concentration of that same crystal may then be used for the vertical position estimate. Au liberated from breccia fragments is a limitation to this technique.

## DISCUSSION AND CONCLUSION

The integration of approaches proposed in this study can play a novel role in Au exploration. The morphological study of Au grains recovered from samples can initially indicate distance from source. By this method, displaced anomalies (e.g. Fletcher 1999) can be differentiated from close-to-source anomalies, and it provides a vector towards the source of Au liberation. By follow-up campaigns it is possible to locate the source within 50 m. This allows the definition of target areas of interest.

However, this method provides no information with respect to source type, present source deposit erosion level and source potential. By coupling the morphological study with Au composition signatures, new information is provided for target evaluation. Composition analysis of Au grain cores can, following the discrimination criteria presented, distinguish different types of source deposits, and in the specific case of Au-rich porphyries, estimate the present deposit erosion level.

The techniques presented have the objective of aiding Au exploration in covered areas. Despite the fact that many additional studies are needed to complement and perfect these techniques, a basic guide for broad use is provided. Limitations of this method include the following.

(1) Coarse Au, especially in Andean environments, may be liberated from large rock fragments already partially transported from the source. This may also occur within glacial environments, with Au liberated from large boulders originally transported from source by moraines. This, in some measure, should be recognizable by a larger variability of Au morphology characteristics, with mixed populations indicating different distances from source.

(2) The presented technique is applicable for visible coarse Au-bearing environments. Fine Au deposits (e.g. Carlin type) are traceable by conventional exploration geochemical techniques.

(3) The type of source deposit and deposit erosion level estimate are limited to those presented. More studies are required for the definition of Au composition signatures in other types of Au-bearing deposits, and their respective erosion levels (vertical zonation). However, this study provides a guide sufficient for an active continental margin environment such as that present in Chile.

(4) This approach provides one more tool out of many used in exploration. The techniques presented here as a guide to Au-source targets may save analytical and sampling costs of a great number of samples, and, if coupled with drilling target definition techniques (e.g. partial extraction geochemistry), may result in significant saving on drilling costs.

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