Ore Mineral Paragenesis of the Gramalote Gold Deposit, Colombia

/ HILDEBRANDO LEAL-MEJÍA (*), JOAN CARLES MELGAREJO, DRAPER

Departament de Cristal·lografia, Mineralogia i Dipòsits Minerals, Facultat de Geologia, Universitat de Barcelona. C/ Martí i Franquès S/N, 08028, Barcelona (España)

INTRODUCTION.

The Gramalote Au Deposit is located in the Department of Antioquia, in the northern Central Cordillera of the Colombian Andes, 230Km NW of Bogotá and 80Km NE of Medellín (Fig. 1).

fig. 1. Location of the Gramalote Gold Deposit.

It has been exploited discontinuously in shallow workings since pre-Colombian times.

Gramalote is hosted by medium to coarse grained tonalite and granodiorite comprising the main phases of the Antioquian Batholith, an irregular shaped poly-phase intrusive, which occupies an area of *ca.* 7800 km^2 (Feininger et al., 1972). The Batholith is crosscut by dykes of aplite, K-spar-quartz pegmatite, porphyritic granodiorite and fine grained diorite. It was emplaced during an important event of metaluminous (I-type), calc-alkaline magmatism which extended approximately from the Albian to the Paleocene (Cediel et al., 2003).

Au mineralization at Gramalote is of the intrusion-related type (Thompson & Newberry, 2000; Lang & Baker, 2001), contained within a structurally controlled network of quartz+Py±Mo+Cpy±Sl veins and veinlets, closely associated with abundant aplite and pegmatite. The principal structural corridors follow two trends: NNW-SSE and roughly NE-SW. Hydrothermal alteration is structurally controlled and restricted to veins and veinlets selvages, In areas of high-density fracturing (>25 veinlets/m), alteration haloes coalesce, forming pervasive zones in which early potassic (K-spar-quartz-pyrite) is often overprinted by phyllic alteration (coarse-grained sericite-muscovite-quartz-pyrite). Surface and drill core samples from the vein network are correlated with high geochemical gold values in both alteration assemblages.

The aim of this contribution is to establish the ore mineral paragenesis within the veins and document vein mineral textures and chemistry.

SAMPLING.

Sampling was carried out over drill core recovered by AngloGold Ashanti Colombia Ltda. Vein samples were selected from the ore-grade zones of the deposit (>1000 ppb Au). Seven drill core samples were selected (Table 1).

SAMPLE ANALYTICAL TECHNIQUES.

Polished-thin sections were examined and SEM-BSE imaging was undertaken at the SCT of the University of Barcelona. EMPA analyses were completed at the University of Oviedo.

MINERAL CHARACTERIZATION.

Pyrite

Pyrite may be the principal vein mineral, or it may occur randomly dispersed within a vein quartz matrix. It generally occurs as massive aggregates, composed by euhedral to subhedral cubic crystals, ranging in size from few hundredths of a μm to various mm. Crystals are optically homogeneous.

Diamond-Drill	Sampled Interval Depth (m)	Average Au (ppb)
GR-DD-5	178-180	2610
GR-DD-8	230-232	3080
GR-DD-13	118-120	14550
GR-DD-14	74-76	8410
	120-122	2780
GR-DD-19	286-288	1720
GR-DD-23	466-468	3070

Table 1. Samples selected for this study.

Chalcopyrite

Chalcopyrite is the second ore mineral in abundance. There are 2 generations: earlier chalcopyrite (Cpy I) appears as small rounded blebs (5 to 20μm) included in pyrite crystals. Later chalcopyrite (Cpy II) is widely distributed, and was introduced later than pyrite. It is found filling primary porosity in open veins, filling small irregular cracks in pyrite, or replacing pyrite along grain borders.

Galena

Galena is found in minor quantity, accompanying Cpy II, and it is directly associated with matildite ($AgBiS_2$). Galena inclusions are anhedral, measuring up to 10 μm in size. Silver content in galena is up to 2.39 wt %.

Sphalerite

Sphalerite crystals are rare. They are Fe-poor (less than 1 wt%) and Cd-rich (up to 4.8 wt%).

Molybdenite

Two generations of molybdenite are apparent, including abundant fine-grained blue-grey "sooty" molybdenite, (Mo (E)) hosted in early, locally sheared quartz veins (pre coarse-pyrite veins), with pyrite and chalcopyrite. These early Mo-bearing veins exhibit strong pink K-spar alteration halos and are commonly low-grade with respect to Au. Later molybdenite (Mo) occurs as occasional small (<10μm) tabular crystals, closely related to Cpy II.

palabras clave: Oro, Colombia, Gramalote, Intrusion-related, Sulfosales.	*key words:* Gold, Colombia, Gramalote, Intrusion-related, Sulphosalts.

* corresponding author: hildebrandolealm@ub.edu

Bi-sulphides and sulphosalts

In order of decreasing abundance these phases include: aikinite ($PbCuBiS_3$), matildite ($AgBiS_2$), pavonite ($(Ag,Cu)(Bi,Pb)_3S_5$), mummeite ($Ag_3CuPbBi_6S_{13}$) and bismuthinite (Bi_2S_3). Grains are ubiquitously small (usually <10μm), and all are anhedral.

Tellurides

Tellurides are very rare and fine-grained. Hessite (Ag_2Te) is scarce; it was observed with Cpy II, aikinite, galena and gold. Tetradymite (Bi_2Te_2S) is less common and, occasionally accompanying gold.

Gold

Au grains occur in 2 types. Type I Au corresponds to inclusions in pyrite crystals and is Ag-poor ($Au_{78-89}Ag_{11-22}$); it forms small rounded grains of intense yellow color, measuring 2-20μm in size (Fig. 2).

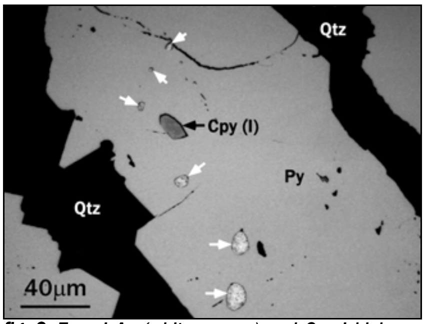

fig. 2. Type I Au (white arrows) and Cpy I blebs as inclusions in pyrite crystals (Py) hosted in quartz (Qtz).

Type II Au is the more abundant. It is observed filling small cracks in complex association with Cpy II and associated Bi-Sulphides and sulphosalts. It is richer in Ag ($Au_{48-74}Ag_{26-52}$), and occurs in variable size fillings up to 150μm, showing curvilinear contacts with Cpy II and its accompanying species. Color tends to be lighter than Type I (Fig. 3).

Given EMPA data plotted on a Au-Ag-Cu atomic % triangular diagram, it is possible to visualize two gold populations which correspond to the two types of gold particles identified by optical microscopy (Fig. 4).

PARAGENETIC SEQUENCE.

Based upon textural observations and chemical characterization of the studied samples, it is possible to establish a

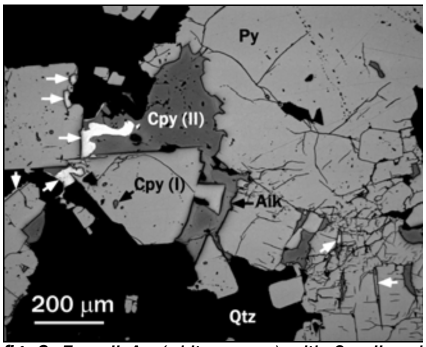

fig. 3. Type II Au (white arrows) with Cpy II and aikinite (Aik). Small rounded inclusions of Cpy I in pyrite (Py) are also observed.

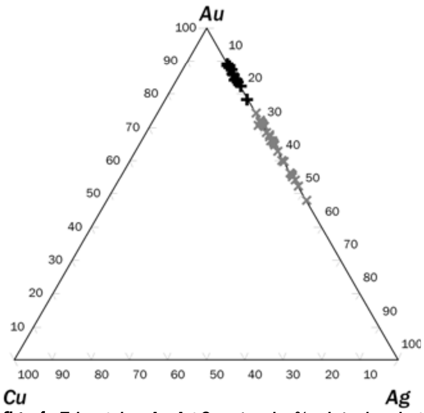

fig. 4. Triangular Au-Ag-Cu atomic % plot showing composition of Type I Au (✚) and Type II Au (✕).

paragenetic sequence which includes at least three stages of ore mineral deposition (Fig. 5):

Stage I is characterized by early (E) quartz-Mo I-Py-(Cpy) veins.

Stage II is characterized by crystallization of medium to coarse pyrite with small blebs of Cpy I and Type I Au.

Stage III is characterized by abundant Cpy II, accompanied by galena, sphalerite, molybdenite, bismuthinite, tellurides, sulphosalts and Type II Au.

CONCLUSIONS.

At least two stages (stages II and III) of Au deposition are recognized at Gramalote. Differences in composition of the Au in the two stages, where later Type II Au is richer in Ag than earlier Type I, suggests that separate stages were accompanied by a decrease in temperature of deposition and concomitant changes in hydrothermal fluid chemistry, as reflected in variations in ore mineral assemblages and changes in wall rock alteration assemblages. The most productive Au

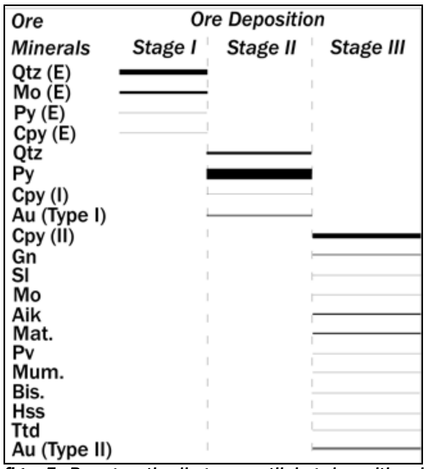

fig. 5. Paragenetic diagram outlining depositional sequence of ore mineral assemblage at Gramalote. Py: pyrite, Cpy: chalcopyrite, Au: gold, Gn: galena, Sl: sphalerite, Mo: molybdenite, Aik: aikinite, Mat.: matildite, Pv: pavonite, Mum.: mummeite, Bis.: bismuthinite, Hss: hessite, Ttd: tetradymite. (E): Early.

pulse was the second (lower temperature) one, characterized by Au with a higher Ag content and a more complex paragenetic mineral association.

Differences in particle size, Au fineness and associated ore mineralogy between the two types of gold should be taken into account during design of beneficiation circuits in any future development of this ore deposit.

ACKNOWLEDGEMENTS.

The authors would like to thank B2Gold Corp. and AngloGold Ashanti Colombia Ltda. for allowing review of logs and geochemical data and selective sampling of drill core. Technical reviews were provided by AGAC geologists Rubén Padilla and Robert Shaw.

REFERENCES.

*Cediel, F., Shaw, R.P. & Caceres, C. (2003): Tectonic Assembly of the Northern Andean Block. In: Bartolini, C., R.T. Buffler, and J. Blickwede, eds., The Circum-Gulf of Mexico and Caribbean: Hydrocarbon habitats, basin formation, and plate tectonics, AAPG Memoir **79**, 815 - 848.*

*Feininger, T., Barrero, D. & Castro, N. (1972): Geología de parte de los departamentos de Antioquia y Caldas (sub-zona II-B). Bol. Geol. (Colombia), **20 (2)**, 173 p.*

*Lang, J.R. & Baker, T. (2001): Intrusion-related gold systems: the present level of understanding. Miner. Deposita, **36**, 477-489.*

*Thompson, J.F.H. & Newberry, R.J. (2000): Gold deposits related to reduced granitic intrusions. Rev. in Econ. Geol., **13**, 377-400.*